# Phytoplankton Pigment Distributions over Seamounts in the Pacific Ocean

by

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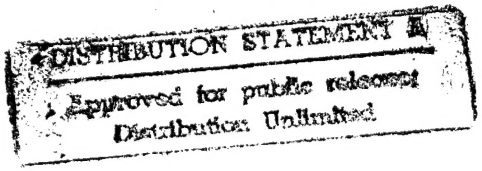
Final Report

Prepared for

Department of the Navy
Office of Naval Research
800 North Quincy Street
Arlington, Virginia 22217-5000

Contract No. N00014-89-J-1832




Report No. CMS-95-03

July 1995

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



| 1. Agency Use Only (Leave blank). | 2. Report Date. July 1995 | 3. Report Type and Dates Covered. Final Technical, April 89 - May 93 |
|---|---|---|

4. Title and Subtitle.

Phytoplankton Pigment Distributions over Seamounts in the Pacific Ocean

5. Funding Numbers.

Program Element No. N00014

Project No. 89-J-1832

Task No.

Accession No.

6. Author(s)
Denis A. Wiesenburg

7. Performing Organization Name(s) and Address(es).
Geochemical and Environmental Research Group
Texas A&M Research Foundation
Box 3578
College Station, TX 77843-3578

8. Performing Organization Report Number

CMS-95-3

9. Sponsoring/Monitoring Agency Name(s) and Address(es).
Department of the Navy
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217-5000

10. Sponsoring/Monitoring Agency Report Number.

11. Supplementary Notes.

Texas A&M Research Foundation Project No, 6296

12a. Distribution/Availability Statement.

Approved for public release; distribution is unlimited.

12b. Distribution Code.

13. Abstract (Maximum 200 words).
Three cruises were conducted during 1989, 1990 and 1991 to study the distribution of phytoplankton pigments over seamounts in the Pacific Ocean. The purpose was to examine the horizontal and vertical distributions of phytoplankton pigments to ascertain the effect seamounts can have on phytoplankton biomass and composition. Vertical profiles of temperature, salinity, *in situ* chlorophyll fluorescence, beam transmission, photosynthetically-active radiation (PAR) and algal pigments were made over Fieberling Guyot, Northeast Bank and Sixtymile Bank as part of the ONR-funded Flow Over Abrupt Topography (TOPO) Accelerated Research Initiative (ARI).

14. Subject Terms.
Seamounts, Pacific Ocean, phytoplankton, pigments, algae, biological oceanography, chlorophyll, CTD, fluorescence

15. Number of Pages. 108

16. Price Code.

| 17. Security Classification of Report | 18. Security Classification of This Page. | 19. Security Classification of Abstract. | 20. Limitation of Abstract. |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | SAR |

## Executive Summary

Three cruises were conducted during 1989, 1990 and 1991 to study the distribution of phytoplankton pigments over seamounts in the Pacific Ocean. The purpose was to examine the horizontal and vertical distributions of phytoplankton pigments to ascertain the effect seamounts can have on phytoplankton biomass and composition. Vertical profiles of temperature, salinity, *in situ* chlorophyll fluorescence, beam transmission, photosynthetically-active radiation (PAR) and algal pigments were made over Fieberling Guyot, Northeast Bank and Sixtymile Bank as part of the ONR-funded Flow Over Abrupt Topography (TOPO) Accelerated Research Initiative (ARI).

The chlorophyll fluorescence maximum in this region of the Pacific Ocean is typically uniform with an average depth of 110 m. Time-dependent vertical excursions of the fluorescence maximum, presumably caused by internal waves, were noted throughout the region with some indication that larger excursions were observed over Fieberling's summit. Total phytoplankton pigment concentrations were low during the TOPO 89 cruise, with chlorophyll-a near 25 ng/L at the surface and averaging only 250 ng/L in the subsurface chlorophyll maximum. Besides chlorophyll *a*, predominant plant pigments in the vertical profiles were zeaxanthin, chlorophyll *b*, fucoxanthin, 19'-butanoyloxyfucoxanthin, and 19'-hexanoyloxyfucoxanthin. Other pigments were virtually absent from the samples. The fluorescence maximum at Fieberling during 1990 was slightly shallower than during 1989. Pigment levels were also lower in 1990, with less than 200 ng/L chlorophyll *a* at the subsurface maximum, compared to ~250 ng/L in 1989. These lower levels probably resulted from lower light levels in 1990 (October vs. September sampling). During both years, fluorescence maxima and pigment levels were lower at Fieberling than at Northeast Bank, where chlorophyll *a* ranged from 400 to 700 ng/L in the subsurface maximum.

We observed that the shape (peakedness) of the fluorescence profile was different above Fieberling Guyot and at the distant stations. The fluorescence levels in the chlorophyll maximum and the chlorophyll a concentration were also lower over the summit of Fieberling Guyot than in the surrounding waters away from the seamount. This difference may be due to differences in zooplankton grazing over and away from the seamount.

## Acknowledgements

The author is indebted to Jennifer Wong, Carrie Neuhard, Kayli Jackson and Michael Ondrusek for analyzing the phytoplankton pigment samples for this program. The assistance of Erik Quiroz in processing the CTD data is gratefully acknowledged. Robert Bidigare was co-investigator of this project and provided the inspiration, expertise and equipment to make the pigment work possible. Paula Bontempi assisted with the graphics and Kelly Thornton helped correct the text. Cruise participants from Texas A&M University were Sung-Ho Kang, Debra DeFreitas, Stephen Sweet David Voegele and Lionel Sanchez.

The scientific party and crew of the R/V New Horizon and R/V Thomas G. Thompson are commended for their outstanding performance. Special thanks are due to fellow cruise scientists Richard Dugdale, Frances Wilkerson, Loren Haury, Peter Wiebe, Lauren Mullineaux, Connie Fay and Chuck Kopczak for their camaraderie and assistance. I wish to thank in particular, Office of Naval Research (ONR) program managers Ann Bucklin, Bernard Zahuranec and Melbourne Briscoe for their guidance and support at the beginning of this project. This research was funded by ONR Grant Number N00014-89-J-1832 to the Texas A&M Research Foundation (Project 6296).

## Contents

## List of Figures

*All Figures Follow the Text of this Report*

## List of Tables

*Tables Follow Each Section of the Report*

## Introduction

Seamounts are known to be sites of substantially higher biomass compared to the deep ocean, yet the reasons for finding more organisms, from benthic invertebrates to pelagic fishes, over and on seamounts are not clear. Several different hypotheses have been developed to explain the distributions of plants and animals over seamounts. Most of these hypotheses depend upon the details of flow around seamounts. While speculation abounds, few studies have been able to provide a sufficient data set to resolve both the flows over and around seamounts and the associated biological variability.

To fill this gap in our knowledge of oceanic processes, in 1987 the U.S. Navy Office of Naval Research (ONR) began an Accelerated Research Initiative (ARI) called Flow Over Abrupt Topography. Preliminary evaluation of the issues involved with flow over abrupt topography led to the development of a program to study the nature of the interactions of the physical, biological and geological environments at a large, isolated seamount. The Flow Over Abrupt Topography project was called TOPO (short for topography). The TOPO program consisted of both physical measurements and modeling (70% effort) and evaluation of biological and geological processes (30% effort). The idea of the program was to combine the expertise of physical, biological and geological oceanographers to address all aspects associated with flow around a large seamount. The goal of TOPO was to address four distinct scientific issues:

1. Residence time of water parcels directly above a seamount,
2. Mixing processes at a seamount,

3. Bottom boundary layer structures at a seamount, and
4. Influence of a seamount on the nearby oceanic environment.

These issues were viewed to be strongly interrelated, as processes on a variety of time scales act to varying degrees to produce the physical, biological and geological oceanic environments at a seamount.

To study these processes without interference, an attempt was made to find an isolated seamount. This task was difficult. Most seamounts are found in chains and are thus separated by only a few tens or perhaps 100 km from a neighbor. By process of elimination, Fieberling Guyot was chosen for this study. Fieberling Guyot had many of the characteristics needed for this study. In 1969, Gunnar Roden had conducted a CTD section across Fieberling from the original R/V Thomas G. Thompson. His data showed perturbations in the temperature, salinity and density fields that appeared to result from the seamount. These features clearly showed upwelling associated with the seamount. Genin and Boehlert (1985) had shown that seamount-associated perturbations at Minami-kasuga Seamount could have an influence upon the distribution of chlorophyll above the seamount summit. Thus, Fieberling Guyot seemed the ideal location to study the interaction of physical and biological processes for this ARI.

**Fieberling Guyot**

Fieberling Guyot is a large seamount which was formed by an extinct volcano which formed on the East Pacific Rise about 20 million years ago. Fieberling (Figure 1) is located 992 km west of San Diego, California. To the east

southeast of Fieberling are three smaller seamounts: Fieberling II (52 km away), Hoke (88 km away) and Stoddard (164 km away). The four seamounts are in a line and probably formed sequentially due to the movement of the Pacific plate over a hot spot in the Earth's mantle. The deep ocean floor in the region has a depth of about 4300 m. Fieberling rises to a minimum depth of 438 m (Figure 2), while the other three seamounts rise to 1040 m (Fieberling II), 772 m (Hoke) and 1070 m (Stoddard). Fieberling Guyot was chosen as the primary site for the TOPO study because it was relatively isolated from other seamounts. While Roden (1991) has noted that Fieberling is isolated only in the upper one-fifth of the water column, it is in this upper one-fifth (including the photic zone) where phytoplankton growth occurs. For the purpose of this study, Fieberling will be considered an isolated seamount.

As seamounts go, the summit plain of Fieberling Guyot is relatively flat. Fieberling's summit is generally considered to be a plain enclosed by the 500 m isobath. The total relief of the summit is less than 200 m. The summit has a 40-m high pinnacle that is believed to be the eroded remnant of a volcanic plug which filled the volcano's magma conduit. A seismic line across the summit of Fieberling shows the relief on the summit (Figure 3).

The concept behind TOPO was to examine processes associated with flow over an abrupt topographic feature. Fieberling Guyot was chosen because it was considered to be in a region of relatively strong flow. Roden (1991) has noted that the impinging flows at the top and bottom of Fieberling are in opposite directions. At depth, the flow is generally from the southwest to northeast. This flow brings water of equatorial origin toward the pole (Reid and Arthur, 1975). Alternately,

the surface flows (of interest to this study) over Fieberling are dominated by the location of the subtropical gyre. Fieberling is located in the eastern, southward moving part of the subtropical gyre, near the outer boundary of the California Current. Figure 4 (from Roden, 1991) shows the location of Fieberling Guyot relative to the California Current and the long term mean Ekman transport for the month of July. Besides being in the meandering end of the California Current, Roden (1991) noted that a pervasive open ocean mesoscale eddy field also surrounds the seamount. The meandering flow in the vicinity of Fieberling was observable in the temperature and salinity fields, satellite-derived chlorophyll *a* concentrations and from the path of satellite-tracked drifters. Because of the complexity of circulation over the seamount, Fieberling Guyot may not have been the ideal location for this study, but no better location was available that was logistically tractable for the TOPO program.

**Northeast Bank**

In addition to studies at Fieberling Guyot, the TOPO water column biology cruises also studied phytoplankton and zooplankton distributions over Northeast Bank and Sixtymile Bank. Only a few phytoplankton pigment stations were taken at Sixtymile Bank on the TOPO 91 cruise. Sixtymile Bank is a small seamount with a very shallow summit (minimum depth 95 m) centered near 32° 05'N 118° 14'W, about 110 km southwest of San Diego, California. The relatively small summit of Sixtymile Bank (5.0 x 3.2 km at 200 m depth) make it much different from either Fieberling Guyot or Northeast Bank. Neither Sixtymile Bank nor the phytoplankton pigment data from it will be discussed in this report.

Northeast Bank is a shallow seamount with a summit centered near 32° 22.1' N 119° 38.3'W. The shallowest depth at Northeast Bank is 357 m. The seamount has a large, relatively flat summit area with a depth less than 400 m. A bathymetry map of Northeast Bank is shown in Figure 5. Phytoplankton pigment samples were collected above Northeast Bank on all three TOPO water column biology cruises. One station was conducted there during 1989, seventeen during 1990 and ten during 1991.

**Phytoplankton Pigments over Seamounts**

Historically, the study of seamounts has been approached from a geological perspective. This bias perhaps originates from an early curiosity as to the geological origin of seamounts. The Challenger Expedition (Murray and Renard, 1881) proliferated this trend when they discovered that seamounts were relatively free of sediments and that only manganese nodules were found on a number of seamounts. Other expeditions focused on the structure and surface features of seamounts to uncover the reasons many seamounts were sediment free. Cores were taken and bottom photography obtained which showed rock outcrops (Heezen et al., 1959) and ripple marks, which are common features of seamounts. These photographs revealed that benthic organisms were more abundant on seamount summits than in the surrounding abyss, and thus benthic biologists joined the ranks of geologists in examining the biota living on and above seamounts (e.g. Bucklin et al., 1987). Thus our knowledge of seamounts has indeed come from the bottom up. Most of the faunal information has come from baited traps (e.g. Wilson et al., 1985) or from bottom trawls (e.g. Maul, 1976).

Surprisingly few studies have been done, and comparatively little is known of the fauna of oceanic seamounts. What is known has been compiled by Wilson and Kaufmann (1987) from the 100 seamounts studied.

Biological data from the water column is limited to studies of fish catches near seamounts and one study (Genin and Boehlert, 1985) of the chlorophyll *a* distribution above one seamount. As it has been shown that physical processes can make the water column above seamounts potential regions of upwelling (e.g. Roden, 1987), there was a need to evaluate the interaction of physical, chemical and biological processes than can change the water column biology above a seamount. This study examined changes in the primary producers, phytoplankton, over Pacific Ocean seamounts.

Besides the light field, some of the important factors which regulate phytoplankton abundance in the ocean include nitrate flux, pycnocline location and vertical stability. In most oceanic regions, these variations are dependent upon vertical and horizontal variations in temperature. In regions where there is flow over abrupt topography, the physical system becomes perturbed and physical forcing factors can alter both the stability and location of the pycnocline and consequently the nitrate flux. The coupling between physical forcing processes and the biological responses to that forcing is a chain of events hinging on increased primary production and resultant higher phytoplankton biomass. Flow over abrupt topography can induce enhanced vertical mixing. This mixing (upwelling) results in the transport of nutrients from depth into the surface layers where available light leads to new production. The higher phytoplankton biomass would induce accelerated zooplankton grazing and an increase in biomass at all

trophic levels. The controlling factor is the specific growth ($d^{-1}$) and the redistribution of the phytoplankton.

Algal pigment concentrations in the marine environment are primarily dependent on the abundance, species composition and photoadaptive state of the phytoplankton present. Thus, accessory chlorophyll and carotenoid pigments can be used as diagnostic markers for investigating algal distribution and associated physiological processes. Detailed pigment measurement, such as those obtained by high performance liquid chromatography (HPLC) analysis, have been successfully used for: (1) "chemotaxonomically" estimating phytoplankton composition (Gieskes and Kraay, 1983a, b; Arnone et al., 1986; Bidigare et al., 1987; Smith et al., 1987; Siegel et al., 1988; Whitledge et al., 1988); (2) assessing the photoadaptive state of natural phytoplankton assemblages (Welschmeyer and Hoepffner, 1986; Bidigare et al., 1987); (3) estimating primary production rates (Bidigare et al., 1987); and (4) qualitatively mapping zooplankton grazing activity (Bidigare et al., 1986; Whitledge et al., 1988). A summary of the current ideas regarding the diagnostic pigments of marine phytoplankton is given in Table 1. These diagnostic pigments are valuable in assessing the biological effects of flow over a seamount.

In undertaking this study of phytoplankton pigment distributions over seamounts, we intended to address several specific scientific questions:

a. Is there enhancement of phytoplankton biomass above Fieberling Guyot resulting from vertical transport of nutrients (specifically nitrate) into surface waters?

b. Does the transition from ammonium to nitrate nitrogen (during periods of

upwelling) produce compositional changes in phytoplankton?

c. Do the plant pigment distributions accurately reflect the extent of the topographically induced upwelling?

d. Does this response contribute significantly to the observed phytoplankton distribution so it can be observed in the far field as downstream patchiness due to shedding of eddies?

e. What is the spatial extent and temporal variability of the seamount induced enhancement in the near field and downstream of the seamount?

We knew when this program began that we would not be able to answer all of these questions. Our goal was to use these questions as a starting point for the study and to modify the objectives as we learned from the results of each of the cruises.

Table 1. List of the important phytoplankton pigments used as diagnostic source markers and their taxonomic physiological significance.

| Pigment | Significance |
|---|---|
| Physiological Markers | |
| Chlorophyll *a* | Algal Biomass and Photosynthestic Potential |
| Chlorophyll *a* | Chlorophyllase-Containing Diatoms |
| Phaeophoribide *a*<br>Phaeophytin *a* | Zooplankton Grazing |
| Carotene<br>Diadinoxanthin<br>Aloxanthin<br>Zeaxanthin | Photo-protectants |
| Green Algae | |
| Chlorophyll *b* | Green Algae |
| Prasinoxanthin | Pransinophytes |
| Golden-brown Algae | |
| Chlorophyll $c_{1+2}$<br>Fucoxanthin | Diatoms (and some Chrysophytes and Prymnesiophytes |
| 19'-Hexanoyloxyfucoxanthin<br>Chlorophyll $c_{2+3}$<br>Fucoxanthin | Prymnesiophytes |
| 19'-Butanoyloxyfucoxanthin<br>Chlorophyll $c_{2+3}$<br>Fucoxanthin | Chrysophytes |
| Peridinin | Dinoflagellates |
| Phycobilin-containing Algae | |
| Zeaxanthin | Coccoid Cyanobacteria |
| Alloxanthin | Cryptophytes |

## Synopsis of Seamount Biology Cruises

During the Flow Over Abrupt Topography (TOPO) Accelerated Research Initiative (ARI), three cruises were conducted primarily to examine water column biological properties. These cruises were conducted in the fall of 1989, 1990 and 1991. The purpose of the 1989 cruise was to make preliminary observations on the biological, chemical and physical properties over and around Fieberling Guyot in order to prepare for the full field year program in 1990. In 1990 and 1991, larger scale water column biology field studies were conducted over Fieberling Guyot and Northeast Bank.

To maximize the scientific resources available to understand the biology seamounts, researchers from several universities were involved in each cruise. Of particular interest to the phytoplankton pigment study, Dr. Richard Dugdale and Frances Wilkerson (University of Southern California) made measurements of nutrient concentrations, carbon fixation and nitrogen cycling to clarify the interactions between physical processes influenced by the seamount and nutrient and production processes. Dr. Loren Haury (Scripps Institution of Oceanography) and Dr. Amatzia Genin (Marine Biological Laboratory, Eilat, Israel) made measurements of vertical distributions of zooplankton biomass and species abundance over and away from Fieberling using Peter Wiebe's 1 $m^2$ MOCNESS zooplankton sampler (333 μm mesh). Our group at Texas A&M University conducted studies of the distribution of phytoplankton pigments by making measurements of chlorophyll florescence with the CTD-mounted fluorometer and

by high performance liquid chromatography on discrete water samples. Our group also provides the processed CTD data for the water column biology cruises and provided water sampling capabilities for the other cruise participants. The following is a brief description of the activities of each of the cruises.

**TOP0 89**

The initial TOPO water column biology cruise was conducted aboard the *R/V New Horizon*. This cruise is commonly referred to as TOPO 89, Leg 3. Dr Loren Haury from Scripps Institution of Oceanography and Dr. Peter Wiebe from Woods Hole Oceanographic Institution were co-chief scientists. The captain was Phil Munsch. The *R/V New Horizon* departed from San Diego, California, on September 8, 1989, and returned to port on September 23, 1989. Table 2 provides a listing of the CTD station number, date, time (UTC), location, maximum CTD depth and number of bottles tripped for each of the stations. Figure 6 shows the location of the stations occupied over Fieberling Guyot during the cruise. One additional station (Station 42) was occupied over Northeast Bank. Its position is shown in Figure 7. The weather was generally good during the entire cruise. The skies were overcast, but the seas were relatively calm. Navigation on this cruise was conducted using a combination of Global Positioning System (GPS) satellites, LORAN and SATNAV, depending upon which system gave the best position for the stations.

The initial CTD survey on this cruise was a star-shaped survey pattern to determine the extent of the physical variability over Fieberling. The star pattern consisted of twelve (12) stations ranging in water depth from 450 m to 4000 m. A

schematic of the star pattern in shown in Figure 8. In addition to this pattern, a series of stations was conducted both over the seamount and at a station far away from Fieberling. On September 18-19, 1989, a northwest to southeast transect line was run over Fieberling Guyot (nine stations) to measure the flows in the upflow-downflow directions.

Before the *R/V New Horizon* reached Fieberling, the bridge spotted an apparently derelict sailboat at 1400 on September 9, 1989. The ship was stopped and the Boston Whaler was launched to investigate. The vessel found was a 32' sloop, the "*Lara*" out of San Francisco. No one was on board. The Coast Guard reported that the *Lara* had been reported missing a few weeks earlier. One man sailing solo had been aboard the vessel when it left San Francisco. It was decided to take the *Lara* in tow while the insurance company made arrangements for her recovery. Towing the boat reduced our speed to about 7 knots but did not interfere with the science, since the slower speed allowed us to process samples between stations at Fieberling. After it became obvious that there would be considerable delay in the insurance company's arranging for a recovery of the boat, the *Lara* was fitted with a radar reflector and a sea anchor and was released. The sailboat was last seen floating toward the south.

**TOPO 90**

The second TOPO water column biology cruise was also conducted aboard the *R/V New Horizon*. Dr. Denis A. Wiesenburg from Texas A&M University was Chief Scientist. The captain was Robert Haines. This cruise is commonly referred to as TOPO 90, Leg 3. The *R/V New Horizon* departed from San Diego, CA, on

September 29, 1990, and returned to port on October 18, 1990. Table 3 provides a listing of the CTD station number, date, time (UTC), location, maximum CTD depth and number of Niskin bottles tripped at each of the CTD stations. Figure 9 shows the location of the stations occupied over Fieberling Guyot during the cruise. Figure 10 shows the location of stations conducted over Northeast Bank during the TOPO 90 cruise. Navigation for all of the CTD stations on this cruise was by GPS. LORAN was used on the cruise only to provide eight locations for activities, and none of these were CTD stations.

Studies of biological, physical and chemical properties were conducted over and around Fieberling Guyot from October 2-11, 1990. Similar studies were undertaken at Northeast Bank from October 13-17, 1990. During this cruise, one of the main challenges at Fieberling Guyot was to redesign our sampling strategies to keep from disturbing the current meter mooring put in place earlier by Ken Brink (Woods Hole Oceanographic Institution) and Charlie Erikson (University of Washington). Based on the information gained from the first cruise, the CTD station location strategy for the second TOPO water column biology cruise was to use transect lines rather than other sampling patterns.

The purpose of this second cruise was to gain a more complete understanding of the biological distribution over Fieberling Guyot, to examine their relationships to the flow field, and to compare the Fieberling Guyot results with a similar set of measurements at Northeast Bank, a seamount with a shallower summit. The sky was always grey during the cruise, and the weather was occasionally too rough to work over the side. Winds of 20-25 knots and 14-16 foot swells were common. In spite of the rough seas for most of the cruise,

most goals of the cruise were accomplished.

The goal of the phytoplankton pigment work on this cruise was to examine the pigment distributions with regard to factors that might influence their distribution, especially zooplankton distribution and current direction. The sampling design of the pigment stations allowed comparisons to be made of pigment distributions over and away from the seamounts. If the abundance of vertically migrating zooplankton is reduced over the seamount thus affecting the patchiness of migrating species in surrounding waters, reduced grazing pressure could result in higher phytoplankton biomass. To assess this potential, several of the CTD-pigment transects were taken along the lines covered by the MOCNESS tows.

**TOPO 91**

The third and final TOPO water column biology cruise was conducted aboard the *R/V Thomas G. Thompson* (AGOR-23). This cruise was the initial scientific cruise aboard the 'new' Thompson. The cruise was designated TGT002A. Dr. Richard Dugdale from the University of Southern California was the Chief Scientist. The *R/V Thompson* departed from San Diego, CA, on September 13, 1991, and returned to San Diego on October 1, 1991. Table 4 provides a listing of the CTD station number, date, time (UTC), location, maximum CTD depth and number of Niskin bottles tripped at each of the CTD stations. Figure 11 shows the location of the station occupied by Fieberling Guyot, and Figure 12 shows the location of stations occupied over Northeast Bank. Additional stations were conducted at greater distances from Fieberling

Guyot and are not shown. Also, the location of the stations occupied at Sixtymile Bank are not plotted. During this cruise, 36 CTD stations were conducted over or in the vicinity of Fieberling Guyot, while ten CTD stations were conducted over Northeast Bank. An additional 12 CTD stations were collected over Sixtymile Bank, a very shallow seamount found in the Pacific Ocean off California at 32° N, 118° W.

Table 2. Station time and position data from the TOPO89 cruise.

| Station | Date | Time (UT) | Latitude (N) | Longitude (W) | Depth (meters) | Niskins |
|---|---|---|---|---|---|---|
| 1 | 09SEP89 | 2353 | 32° 33.37' | 122° 27.85' | 514 | 12 |
| 2 | 11SEP89 | 1516 | 32° 25.92' | 127° 46.91' | 488 | 4 |
| 3 | 11SEP89 | 1640 | 32° 26.34' | 127° 47.37' | 253 | 12 |
| 4 | 11SEP89 | 2356 | 32° 31.55' | 127° 47.42' | 1009 | 12 |
| 5 | 12SEP89 | 0234 | 32° 33.75' | 127° 57.92' | 1010 | 12 |
| 6 | 12SEP89 | 0543 | 32° 26.74' | 127° 52.70' | 1010 | 12 |
| 7 | 12SEP89 | 0823 | 32° 21.03' | 127° 58.97' | 1018 | 12 |
| 8 | 12SEP89 | 1116 | 32° 21.25' | 127° 49.28' | 1011 | 12 |
| 9 | 12SEP89 | 1342 | 32° 15.18' | 127° 44.78' | 1008 | 12 |
| 10 | 12SEP89 | 1553 | 32° 21.99' | 127° 41.82' | 250 | 12 |
| 11 | 12SEP89 | 1800 | 32° 22.58' | 127° 41.94' | 1015 | 12 |
| 12 | 13SEP89 | 0658 | 32° 35.69' | 127° 41.10' | 1012 | 12 |
| 13 | 13SEP89 | 0911 | 32° 28.59' | 127° 41.01' | 1011 | 12 |
| 14 | 13SEP89 | 1135 | 32° 24.32' | 127° 34.08' | 1009 | 12 |
| 15 | 13SEP89 | 1353 | 32° 25.90' | 127° 46.66' | 459 | 12 |
| 16 | 13SEP89 | 1615 | 32° 26.10' | 127° 46.88' | 450 | 12 |
| 17 | 14SEP89 | 1350 | 32° 24.89' | 128° 17.91' | 1018 | 12 |
| 18 | 14SEP89 | 1552 | 32° 25.12' | 128° 18.06' | 504 | 12 |
| 19 | 15SEP89 | 1557 | 32° 26.01' | 127° 46.67' | 455 | 12 |
| 20 | 15SEP89 | 1704 | 32° 25.78' | 127° 46.78' | 462 | 12 |
| 21 | 16SEP89 | 0218 | 32° 26.01' | 127° 46.64' | 470 | 12 |
| 22 | 16SEP89 | 1601 | 32° 25.92' | 127° 46.60' | 457 | 12 |
| 23 | 16SEP89 | 1715 | 32° 25.66' | 127° 46.90' | 459 | 12 |
| 24 | 16SEP89 | 1838 | 32° 25.93' | 127° 46.61' | 460 | 12 |
| 25 | 17SEP89 | 0251 | 32° 25.01' | 128° 18.18' | 510 | 0 |
| 26 | 17SEP89 | 1637 | 32° 24.85' | 128° 18.10' | 1019 | 12 |
| 27 | 17SEP89 | 1741 | 32° 25.02' | 128° 18.02' | 522 | 12 |
| 28 | 17SEP89 | 1900 | 32° 25.10' | 128° 18.04' | 511 | 12 |
| 29 | 17SEP89 | 2218 | 32° 26.78' | 127° 53.35' | 1506 | 12 |
| 30 | 18SEP89 | 0114 | 32° 24.64' | 127° 47.26' | 255 | 12 |
| 31 | 18SEP89 | 2306 | 32° 34.25' | 128° 8.41' | 1019 | 12 |
| 32 | 19SEP89 | 0136 | 32° 30.55' | 128° 1.67' | 1020 | 12 |
| 33 | 19SEP89 | 0340 | 32° 29.61' | 127° 54.73' | 1016 | 12 |
| 34 | 19SEP89 | 0549 | 32° 27.79' | 127° 50.15' | 704 | 12 |
| 35 | 19SEP89 | 0732 | 32° 27.28' | 127° 47.05' | 465 | 12 |
| 36 | 19SEP89 | 0920 | 32° 25.23' | 127° 42.94' | 529 | 12 |
| 37 | 19SEP89 | 1134 | 32° 24.07' | 127° 38.35' | 1016 | 12 |
| 38 | 19SEP89 | 1358 | 32° 21.34' | 127° 31.45' | 1017 | 12 |
| 39 | 19SEP89 | 1545 | 32° 19.05' | 127° 24.79' | 252 | 12 |
| 40 | 19SEP89 | 1752 | 32° 19.10' | 127° 24.65' | 1010 | 12 |
| 41 | 19SEP89 | 1901 | 32° 20.60' | 127° 24.91' | 250 | 4 |
| 42 | 22SEP89 | 0202 | 32° 22.08' | 119° 38.31' | 357 | 12 |

Table 3. Station time and position data from the TOPO90 cruise.

| Station | Date | Time (UT) | Latitude (N) | Longitude (W) | Depth (meters) | Niskins |
|---|---|---|---|---|---|---|
| 1 | 30SEP90 | 2312 | 32° 37.73' | 121° 4.78' | 509 | 12 |
| 2 | 02OCT90 | 1840 | 32° 26.69' | 127° 47.63' | 509 | 11 |
| 3 | 02OCT90 | 2211 | 32° 26.59' | 127° 43.87' | 490 | 12 |
| 4 | 02OCT90 | 2838 | 32° 26.57' | 127° 45.16' | 400 | 11 |
| 5 | 03OCT90 | 0405 | 32° 19.92' | 127° 48.02' | 503 | 10 |
| 6 | 03OCT90 | 1620 | 32° 26.72' | 127° 47.65' | 250 | 12 |
| 7 | 04OCT90 | 1307 | 32° 30.26' | 127° 43.40' | 498 | 12 |
| 8 | 04OCT90 | 1626 | 32° 26.68' | 127° 47.76' | 458 | 12 |
| 9 | 04OCT90 | 1854 | 32° 24.73' | 127° 45.38' | 456 | 12 |
| 10 | 04OCT90 | 2140 | 32° 26.95' | 127° 44.35' | 406 | 12 |
| 11 | 05OCT90 | 1143 | 32° 28.60' | 127° 44.09' | 506 | 12 |
| 12 | 05OCT90 | 1352 | 32° 23.31' | 127° 45.99' | 504 | 12 |
| 13 | 05OCT90 | 1606 | 32° 26.68' | 127° 47.65' | 477 | 12 |
| 14 | 05OCT90 | 1837 | 32° 26.04' | 127° 44.77' | 405 | 12 |
| 15 | 05OCT90 | 2024 | 32° 21.29' | 127° 46.72' | 505 | 12 |
| 16 | 05OCT90 | 2215 | 32° 20.04' | 127° 47.14' | 508 | 12 |
| 17 | 06OCT90 | 1611 | 32° 26.78' | 127° 47.50' | 508 | 12 |
| 18 | 06OCT90 | 1751 | 32° 28.68' | 127° 46.23' | 501 | 12 |
| 19 | 06OCT90 | 1935 | 32° 30.26' | 127° 44.37' | 500 | 12 |
| 20 | 06OCT90 | 2107 | 32° 33.19' | 127° 42.56' | 508 | 12 |
| 21 | 06OCT90 | 2242 | 32° 35.75' | 127° 40.76' | 502 | 11 |
| 22 | 07OCT90 | 1828 | 32° 25.14' | 127° 49.92' | 503 | 12 |
| 23 | 07OCT90 | 1612 | 32° 26.75' | 127° 47.57' | 452 | 12 |
| 24 | 07OCT90 | 1813 | 32° 22.75' | 127° 50.71' | 506 | 12 |
| 25 | 07OCT90 | 2034 | 32° 20.26' | 127° 52.77' | 502 | 12 |
| 26 | 07OCT90 | 2224 | 32° 17.77' | 127° 54.82' | 518 | 12 |
| 27 | 08OCT90 | 1615 | 32° 26.65' | 127° 47.61' | 505 | 12 |
| 28 | 08OCT90 | 2221 | 32° 22.98' | 127° 40.84' | 506 | 12 |
| 29 | 08OCT90 | 2342 | 32° 24.46' | 127° 43.28' | 506 | 12 |
| 30 | 09OCT90 | 1616 | 32° 26.68' | 127° 47.66' | 505 | 12 |
| 31 | 09OCT90 | 1812 | 32° 25.76' | 127° 45.49' | 405 | 12 |
| 32 | 09OCT90 | 2027 | 32° 28.01' | 127° 49.79' | 500 | 12 |
| 33 | 09OCT90 | 2157 | 32° 29.34' | 127° 50.89' | 508 | 12 |
| 34 | 10OCT90 | 1619 | 32° 27.04' | 127° 47.03' | 404 | 12 |
| 35 | 10OCT90 | 2026 | 32° 30.24' | 127° 54.56' | 505 | 12 |
| 36 | 10OCT90 | 2244 | 32° 31.15' | 127° 54.64' | 1514 | 12 |
| 37 | 11OCT90 | 1611 | 32° 26.71' | 127° 47.65' | 507 | 12 |
| 38 | 13OCT90 | 2330 | 32° 20.20' | 119° 39.35' | 356 | 12 |
| 39 | 14OCT90 | 1554 | 32° 20.09' | 119° 39.35' | 355 | 12 |
| 40 | 14OCT90 | 1742 | 32° 16.71' | 119° 37.13' | 352 | 12 |
| 41 | 14OCT90 | 1835 | 32° 17.90' | 119° 37.89' | 350 | 12 |
| 42 | 14SEP89 | 1937 | 32° 19.04' | 119° 38.37' | 346 | 12 |

Table 3 (continued). Station time and position data from the TOPO90 cruise.

| Station | Date | Time (UT) | Latitude (N) | Longitude (W) | Depth (meters) | Niskins |
|---|---|---|---|---|---|---|
| 43 | 14OCT90 | 2056 | 32° 20.74' | 119° 39.45' | 349 | 12 |
| 44 | 14OCT90 | 2208 | 32° 22.00' | 119° 40.11' | 347 | 12 |
| 45 | 14OCT90 | 2307 | 32° 23.39' | 119° 40.88' | 353 | 12 |
| 46 | 14OCT90 | 0015 | 32° 25.43' | 119° 42.29' | 352 | 12 |
| 47 | 15OCT90 | 1539 | 32° 19.95' | 119° 38.96' | 349 | 12 |
| 48 | 15OCT90 | 1755 | 32° 19.01' | 119° 48.18' | 176 | 12 |
| 49 | 15OCT90 | 1851 | 32° 19.98' | 119° 48.94' | 353 | 12 |
| 50 | 15OCT90 | 1949 | 32° 20.89' | 119° 49.52' | 352 | 12 |
| 51 | 15OCT90 | 2136 | 32° 22.49' | 119° 50.19' | 354 | 12 |
| 52 | 15OCT90 | 2216 | 32° 23.44' | 119° 51.01' | 352 | 12 |
| 53 | 16OCT90 | 1531 | 32° 20.03' | 119° 38.96' | 354 | 12 |
| 54 | 16OCT90 | 1752 | 32° 19.11' | 119° 38.41' | 351 | 0 |
| 55 | 16OCT90 | 1835 | 32° 21.01' | 119° 39.64' | 353 | 0 |
| 56 | 16OCT90 | 1921 | 32° 22.19' | 119° 40.30' | 355 | 0 |
| 57 | 16OCT90 | 2001 | 32° 23.50' | 119° 40.98' | 355 | 0 |
| 58 | 17OCT90 | 0143 | 32° 16.57' | 119° 35.66' | 1101 | 12 |

Table 4. Station and position data from the TOPO91 cruise.

| Station | Date | Time (UT) | Latitude (N) | Longitude (W) | Depth (meters) | Niskins |
|---|---|---|---|---|---|---|
| 1 | 13SEP91 | 2127 | 32° 26.31' | 122° 31.89' | 510 | 11 |
| 2 | 14SEP91 | 1619 | 32° 27.10' | 127° 45.02' | 509 | 12 |
| 3 | 15SEP91 | 1916 | 32° 26.03' | 127° 45.33' | 409 | 12 |
| 4 | 15SEP91 | 2157 | 32° 24.10' | 127° 46.30' | 504 | 12 |
| 5 | 15SEP91 | 0025 | 32° 22.00' | 127° 47.00' | 505 | 12 |
| 6 | 16SEP91 | 1612 | 32° 24.19' | 127° 46.40' | 505 | 12 |
| 7 | 16SEP91 | 1829 | 32° 26.10' | 127° 45.59' | 455 | 12 |
| 8 | 16SEP91 | 2038 | 32° 27.43' | 127° 44.81' | 450 | 12 |
| 9 | 16SEP91 | 2246 | 32° 29.10' | 127° 44.20' | 503 | 12 |
| 10 | 17SEP91 | 1617 | 32° 25.94' | 127° 45.51' | 492 | 12 |
| 11 | 17SEP91 | 1852 | 32° 25.18' | 127° 43.13' | 505 | 12 |
| 12 | 17SEP91 | 2155 | 32° 24.72' | 127° 40.75' | 505 | 12 |
| 13 | 17SEP91 | 2351 | 32° 24.17' | 127° 38.41' | 505 | 12 |
| 14 | 18SEP91 | 1615 | 32° 29.05' | 127° 44.38' | 505 | 12 |
| 15 | 18SEP91 | 2218 | 32° 31.10' | 127° 43.38' | 501 | 12 |
| 16 | 18SEP91 | 0100 | 32° 33.20' | 127° 42.60' | 504 | 12 |
| 17 | 19SEP91 | 1823 | 32° 25.47' | 127° 43.23' | 504 | 12 |
| 18 | 19SEP91 | 2106 | 32° 27.61' | 127° 50.33' | 501 | 12 |
| 19 | 19SEP91 | 2318 | 32° 27.78' | 127° 52.68' | 500 | 12 |
| 20 | 20SEP91 | 1820 | 32° 27.61' | 127° 50.03' | 497 | 12 |
| 21 | 20SEP91 | 2246 | 32° 26.61' | 127° 48.13' | 501 | 12 |
| 22 | 20SEP91 | 0102 | 32° 27.83' | 127° 52.67' | 501 | 12 |
| 23 | 21SEP91 | 1720 | 32° 27.35' | 127° 50.28' | 501 | 12 |
| 24 | 21SEP91 | 2035 | 32° 26.71' | 127° 47.80' | 250 | 12 |
| 25 | 21SEP91 | 2242 | 32° 26.71' | 127° 48.53' | 250 | 12 |
| 26 | 21SEP91 | 0019 | 32° 27.00' | 127° 48.90' | 250 | 12 |
| 27 | 21SEP91 | 0141 | 32° 27.20' | 127° 49.40' | 250 | 12 |
| 28 | 22SEP91 | 1706 | 32° 27.13' | 127° 50.05' | 252 | 12 |
| 29 | 22SEP91 | 1904 | 32° 27.50' | 127° 50.20' | 250 | 12 |
| 30 | 22SEP91 | 2036 | 32° 27.38' | 127° 51.06' | 250 | 12 |
| 31 | 22SEP91 | 0014 | 32° 36.53' | 128° 24.88' | 250 | 12 |
| 32 | 23SEP91 | 1625 | 32° 38.59' | 128° 29.88' | 505 | 12 |
| 33 | 23SEP91 | 2056 | 32° 25.86' | 127° 45.52' | 498 | 12 |
| 34 | 23SEP91 | 2259 | 32° 25.32' | 127° 42.99' | 504 | 12 |
| 35 | 24SEP91 | 0057 | 32° 24.17' | 127° 46.32' | 503 | 12 |
| 36 | 24SEP91 | 1519 | 32° 27.41' | 127° 52.92' | 503 | 12 |
| 37 | 25SEP91 | 2311 | 32° 18.03' | 119° 38.27' | 349 | 11 |
| 38 | 26SEP91 | 0042 | 32° 18.83' | 119° 38.38' | 353 | 11 |
| 39 | 26SEP91 | 0218 | 32° 19.95' | 119° 38.96' | 355 | 12 |
| 40 | 27SEP91 | 1015 | 32° 20.80' | 119° 49.69' | 352 | 12 |
| 41 | 27SEP91 | 1206 | 32° 23.39' | 119° 40.88' | 334 | 12 |
| 42 | 27SEP91 | 1329 | 32° 22.03' | 119° 40.09' | 354 | 12 |

Table 4 (continued). Station and position data from the TOPO91 cruise.

| Station | Date | Time (UT) | Latitude (N) | Longitude (W) | Depth (meters) | Niskins |
|---|---|---|---|---|---|---|
| 43 | 27SEP91 | 1509 | 32° 20.74' | 119° 39.45' | 354 | 11 |
| 44 | 27SEP91 | 1601 | 32° 19.95' | 119° 39.07' | 354 | 12 |
| 45 | 28SEP91 | 0044 | 32° 4.83' | 118° 17.60' | 504 | 12 |
| 46 | 28SEP91 | 0204 | 32° 5.01' | 118° 13.83' | 102 | 12 |
| 47 | 28SEP91 | 1344 | 32° 13.54' | 118° 10.43' | 504 | 12 |
| 48 | 28SEP91 | 1528 | 32° 10.46' | 118° 11.45' | 505 | 12 |
| 49 | 28SEP91 | 1722 | 32° 7.67' | 118° 12.22' | 504 | 12 |
| 50 | 28SEP91 | 1905 | 32° 1.48' | 118° 15.50' | 353 | 12 |
| 51 | 28SEP91 | 2043 | 31° 58.50' | 118° 16.60' | 501 | 12 |
| 52 | 28SEP91 | 2236 | 31° 56.11' | 118° 17.74' | 501 | 12 |
| 53 | 29SEP91 | 1554 | 32° 5.31' | 118° 14.56' | 104 | 12 |
| 54 | 29SEP91 | 1746 | 32° 4.90' | 118° 16.99' | 505 | 12 |
| 55 | 29SEP91 | 1953 | 32° 4.93' | 118° 10.99' | 505 | 12 |

## Instrumentation, Calibration and Sampling Procedures

Our philosophy of hydrographic data collection was to go to sea with a complete set of operational, calibrated equipment designed to provide the highest quality data set possible. The sea-going equipment that was used for this portion of the TOPO program was purchased specifically for this purpose.

### Conductivity/Temperature/Depth System

The primary system for continuous measurements during TOPO water column biology cruises was a Sea-Bird Electronics, Inc. SBE-911 conductivity-temperature-depth (CTD) system used with an SBE-11 deck unit. The Sea-Bird SBE-911 CTD is a research grade system which offers high quality profiles of oceanic temperature, conductivity, and pressure to all ocean depths. The SBE-911 uses ultra-stable, time-response matched sensors and fast, high-resolution parallel sampling for data acquisition.

The Sea-Bird SBE-911 CTD uses bolt-on temperature and conductivity sensors which have an established record for reliability and long-term dependability. A Paroscientific Digiquartz pressure transducer with temperature compensated output is used for pressure measurement. A pump is used on the conductivity sensor to match its dynamic response to that of the temperature sensor. All sensors have frequency outputs that are individually digitized in the underwater unit 24 times per second. The digitized data are transmitted from the underwater unit via a single conductor armored cable to the shipboard processor.

This deck unit (SBE-11) decodes the incoming data and computes sensor frequencies. The binary equivalent of these frequencies is output to a controlling computer (IBM-PC compatible 286 computer with a floating point accelerator chip) using an IEEE-488 communication link. The computer logs the data on disk and uses instrument calibration data and sensor algorithms to compute temperature, conductivity, salinity, and depth. Additionally, the data (audio tones) from the CTD can be recorded on cassette tapes which can be replayed later if problems are encountered with the digital data recording. Specifications for the SBE-911 CTD are given in Table 5.

**Hydrographic Measurements**

Oceanographic equipment used over-the-side on the TOPO water column biology cruises included a 12 Niskin bottle Rosette system and a Sea-Bird 911 CTD. In addition to providing precise measurements of temperature and salinity with depth, the CTD system is a general-purpose data acquisition and telemetry system. Data interfaces are provided by Sea-Bird which allow simple interfacing of additional sensors for measuring fluorometry, transmissivity, and downwelling irradiance. On the LATEX hydrography cruises, these extra data channels were used to interface the CTD to a SeaTech, Inc. fluorometer, a Biospherical Instruments irradiance sensor and a SeaTech, Inc. transmissometer. Sea-Bird Electronics also provides data processing software which allows processing and display of data in real-time. This capability allowed the TOPO CTD operator to use the data collected during the CTD downcast to make informed decisions about what depths to sample on the upcast using the attached Rosette sampling system.

**Phytoplankton Pigment Measurements**

Phytoplankton pigment samples were collected at 30 to 50 stations during each of the TOPO water column biology cruises. Water samples were collected from the Niskin bottles at depths determined by the CTD operator based on the real-time fluorescence profiles measured by the *in situ* fluorometer attached to the CTD system. Samples were collected from selected stations chosen to maximize both the areal coverage and ensure that a wide range of pigment levels is sampled. The phytoplankton pigment samples are collected in one-liter, brown plastic bottles. As the water flows from the Niskin bottle into the plastic bottle, it passes through a mesh Nitex screen which removes zooplankton from the pigment samples. Samples were collected in duplicate from each sampling depth.

In the shipboard laboratory, one-liter water samples were filtered in duplicate through Whatman GF/F fiberglass filters (47 mm) under low-to-moderate vacuum. The filters were frozen in liquid nitrogen immediately after collection and are returned to Texas A&M University for analysis in the GERG pigment laboratory. There the filters were removed from the liquid nitrogen and extracted in 5.4 ml 100% acetone (containing an appropriate internal standard) under subdued light. Samples are then vortexed and allowed to extract for 24 hours in the dark at -20°C. Following extraction, samples were centrifuged for five minutes to remove cellular debris. Chlorophyll and carotenoid pigments were separated using a Spectra-Physics Model SP8700 liquid chromatograph and Radial-PAK C18 (8 x 100 mm column; 5-5 m particles) at a flow rate of 6 ml per min. Prior to injection, a 1 ml aliquot of the pigment standards or algal extract was mixed with 300 µl of ion-pairing solution (15 g tetrabutylammonium acetate

and 77 g ammonium acetate in one liter of distilled water; Mantoura and Llewellyn 1983). A two-step solvent program was used to separate the various pigments extracted from the natural samples. After injection (500 µl sample), mobile phase A (80:15:5; methanol:water:ion-pairing solution) was ramped to mobile phase B (methanol) over a 12 min period. Mobile phase B was then pumped for 20 min, for a total analysis time of 32 min.

Individual chlorophyll and carotenoid peaks were detected and quantified by area with a Waters Model 440 Fixed Wavelength Detector (436 nm) and a Hewlett-Packard Model 3392A integrator, respectively. Phaeophorbides and phaeophytins were detected and quantified (by area) with a Waters Model 420-AC Fluorescence Detector (EXl: 400-460 nm; EMl:>600 nm) and a Hewlett-Packard Model 3392A integrator, respectively. Peak identities of the pigment extracts were determined by comparing their retention times with pure standards and extracts prepared from "standard" plant materials (*Emiliana huxleyi*, *Phaeodactylum tricornutum*, *Pelagococcus subviridis,* spinach, etc.) of known pigment composition. On-line diode array spectroscopy (400-700 nm; Hewlett-Packard Model HP8451 Diode Array Spectrophotometer) was used to confirm the identities of the major chlorophylls, carotenoids, phaeophorbides, and phaeophytins.

Pigment standards were obtained from Sigma Chemical Co. (chlorophylls a, b, and b-carotene) or were purified by preparative-scale HPLC. Concentrations of the pigment standards were determined spectrophotometrically in one-cm cuvettes using published extinction coefficients. Known pigment quantities were injected and resultant peak areas were used to calculate individual standard

response factors (ng pigment per area). Pigment concentrations (ng pigment per liter) of the samples then were calculated based on these response factors and knowledge of the filtration and extraction volumes.

**Downwelling Irradiance**

Continuous profiles of downwelling irradiance were measured at each hydrographic station using a Biospherical Instruments, Inc., Model QSP-200L irradiance-profiling sensor. The QSP-200L is a light transducer specifically designed to measure widely variant light fields in the ocean in conjunction with CTD systems. The QSP-200L has a logarithmic output which is consistent with the inherently depth-dependent exponential decay of light in the ocean. The logarithmic output allows accurate measurements over four decades of light intensity, ranging from 0.01 to 100% of full sunlight. The heart of the QSP-200L is a blue-enhanced, high-stability, silicon photovoltaic detector with dielectric and absorbing glass filter assembly. The output voltage from the irradiance sensor is digitized by the Sea-Bird CTD and transmitted to the deck along with the CTD data. The irradiance data in Einstein$\cdot s^{1}$ $m^{-2}$ are processed and displayed in real-time by the Sea-Bird CTD data acquisition software along with the other continuous profile parameters.

The QSP-200L has a spectral response designed to measure photosynthetically available radiation (PAR) between 400 and 700 nanometers with an equal quanta response. The QSP-200L is configured with a scalar $2\pi$, "omnidirectional" irradiance optical collector. The QSP-200L downwelling irradiance sensor is entirely modular. The sensor and sensor interface electronics

occupy a sealed, self-contained pressure housing. The irradiance sensor has a cylindrical shape with a length of 15 cm and a diameter of 7 cm. This unit is attached to the top of the CTD-Rosette package to ensure that the light sensor is not shaded during lowering. This modular configuration allows for ease of installation, service, and calibration. A malfunctioning sensor can quickly and easily be exchanged at sea. The QSP-200L sensor was calibrated yearly by Biospherical Instruments using a NIST traceable, 1000-watt type FEL Standard of Spectral Irradiance.

**Fluorometry and Transmissometry**

A SeaTech, Inc. in situ fluorometer was used to make continuous vertical measurements of chlorophyll fluorescence. This unit was set to maximum sensitivity during all cruises. Fluorescence data were collected with the unit set for one second time averaging. The ability of the CTD operator to have real-time vertical fluorescence profiles allowed the collection of water samples that would well-define the vertical phytoplankton pigment gradients in the study area.

In addition to the transmissometer, a SeaTech, Inc. 25 cm transmissometer was used to make measurements of the turbidity. The SeaTech transmissometer uses a 660 nm wavelength light beam, the attenuation of which is used to measure the absorption of particles. This instrument has some limitations in that it is more sensitive to smaller particles than to larger ones, but it proved useful in revealing the small surface-water plankton that have low chlorophyll biomass.

Table 5. Specifications of Sea-Bird Electronics, Inc., SBE-911 conductivity, temperature, depth (CTD) underwater unit used on TOPO water column biology cruises.

| | |
|---|---|
| Measurement Range: | |
| Temperature | -5°C to +35°C |
| Conductivity | 0 to 7 S/m (0 to 70 mmho/cm) |
| Depth | 0 to 6800 m |
| Accuracy: | |
| Temperature | 0.004°C (typical, 0.01 per 6-months guaranteed) |
| Conductivity | 0.003 S/m/month (typical, 0.001/month guaranteed) |
| Depth | 0.05% of full scale over the ambient temperature range of 0. to 25°C (typical, 0.1% guaranteed) |
| | 0.02% with temperature compensation installed |
| Resolution: | |
| Temperature | 0.0003°C |
| Conductivity | 0.00004 S/m |
| Depth | 0.004% of full scale |
| Response Time: | |
| Temperature | 0.082 sec (0.5 m/sec drop) |
| | 0.070 sec (1.0 m/sec drop) |
| Conductivity (pumped) | 0.084 sec (0.5 m/sec drop) |
| | 0.070 sec (1.0 m/sec drop) |
| Conductivity (no pump) | 0.170 sec (2.0 m/sec drop) |
| Depth | 0.001 sec |

Materials:
6000 Meter Pressure Case 7075-T6 anodized aluminum,
5 inches OD with 0.5 inches wall thickness, zinc anode protected

Weight:
24 kg in air, 15 kg in water, for a standard system with pump option. For work to depths beyond a few hundred meters, additional weight is added to minimize wire angle.

Size:
1.1 m x 0.2 m x 0.3 m, rectangular cage shape to minimize danger of rolling while stored or being serviced.

## Synopsis of Cruise Results

During the three TOPO water column biology cruises, a large data set was collected for phytoplankton pigments. In addition, over 150 vertical profiles of temperature, salinity and fluorescence were made at three different Pacific Ocean seamounts. The quantity of data collected on these cruises is given in Table 6. Flow disturbances induced by Fieberling Guyot are suspected of influencing nutrient and productivity distributions in its vicinity (Wilkerson et al., 1990). The hypothesis is that physical processes related to Taylor caps entrain nutrients into the deeper part of the euphotic zone (i.e. 100-150 m depth) near the seamount. If sufficient light is available, new primary productivity will be enhanced. In addition, higher rates of regenerated productivity (ammonium uptake) may result from the abundance of migratory zooplankton observed near seamounts.

The observational approach for TOPO relied on detailed measurements of the horizontal and vertical distributions of nutrients and productivity as well as studies of the metabolic state and irradiance-uptake relationships of phytoplankton. Because Fieberling Guyot is located in the oligotrophic outer edge of the California Current, nutrient levels were virtually undetectable in the euphotic zone using standard analytical techniques. As a result, on all cruises, nitrate was measured by Dugdale and Wilkerson to nanomolor levels (Cox, 1980, Garside, 1982) in parallel with micromolar (Autoanalyzer) measurements of nitrate, nitrite, ammonium, silicate and phosphate.

The phytoplankton pigment cruise results from the TOPO program are discussed briefly below. Only the results from TOPO 89 and TOPO 90 are

presented, although all of the data are given in Appendix A. A reduction in funding during the last year of TOPO prohibited more than the analysis of samples from the TOPO 91 cruise.

**TOPO 89 Results**

During the 1989 TOPO cruise, vertical profiles of algal pigments and *in situ* fluorescence over Fieberling Guyot were used to assess the potential effect of sea bottom topography on the distribution of phytoplankton. The preliminary results from the cruise were discussed by Wiesenburg et al. (1990). If perturbations in the flow field affect nutrient distributions or primary production, these changes will be reflected in modified algal pigment distributions. Transportation of an algal population that is nutrient rich, but light limited, to shallower depths would increase primary production. Seamount-induced changes in zooplankton concentration would also affect phytoplankton distributions due to variations in grazing patterns or intensity.

During the September 1989 cruise, the fluorescence profiles exhibited a regular pattern throughout the study area with a distinct maximum between 100 and 125 m. The fluorescence maximum in this region of the Pacific Ocean is typically uniform with an average depth of 110 m. Time-dependent vertical excursions of the fluorescence maximum, presumably caused by internal waves, were noted throughout the region with some indication that larger excursions were observed over Fieberling's summit.

An example of these changes in depth of the subsurface fluorescence (chlorophyll) maximum is shown in Figure 13. This vertical plot of relative

fluorescence versus depth (0-250 meters) was made from a series of rapid CTD deployments over the Fieberling Guyot summit on September 18, 1989. A series of eleven (11) CTD profiles was collected over a three-hour period. The time between CTD lowerings was varied between 13 and 19 minutes to reduce the possibility of time-aliasing the data. The mode time between lowerings was 14 minutes. During this three-hour period, vertical excursions of the fluoresence maximum up to 20 m were observed. The possible significance of this vertical movement of the chlorophyll maximum is that nutrient rich, light-starved phytoplankton could be transported into regions of higher irradiance due to the movement of the chlorophyll maximum. Since plankton that are well-adapted to low light levels are superior harvesters of photons, even a small increase in irradiance levels could contribute to the primary production in the area. If the vertical excurisons in the chlorophyll maximum were higher over the seamount than in the open water, this process might contribute to the higher levels of biomass typically found on top of seamounts. While our work during TOPO could not confirm this theory, it warrants further study.

Total phytoplankton pigment concentrations were low during TOPO 89, with chlorophyll-a near 25 ng/L at the surface and averaging only 250 ng/L in the subsurface chlorophyll maximum. Besides chlorophyll *a*, predominant plant pigments in the vertical profiles were zeaxanthin, chlorophyll *b*, fucoxanthin, 19'-butanoyloxyfucoxanthin, and 19'-hexanoyloxyfucoxanthin. Other pigments were virtually absent from the samples.

For this initial TOPO cruise, a comparison was made of the general pigment distributions over and away from Fieberling Guyot. For this analysis, surface and

chlorophyll maximum pigment values were averaged for stations over Fieberling (500 m depth), on the Fieberling flank (2000 m depth) and away (4000 m depth) from Fieberling. The stations examined were 3, 30 and 35 (over), 5, 7, 9, 12 and 14 (flank) and 4, 6, 8, 11 and 13 (away). The average mean phytoplankton pigment values for the surface and chlorophyll maximum are given in Table 7. For the purpose of this comparison, the samples averaged for the chlorophyll maximum are all those from the designated stations in a depth range of 90 to 120 meters (typically 4 or 5 samples per station). The surface mean values are from all samples at the designated station less than 15 m (typically 1 or 2 samples per station). To compare the relative proportions of phytoplankton pigments in the same three locations, pie diagrams were constructed for the same three Fieberling locations. These pie charts are shown in Figure 14, 15, and 16. The general, surface-water pigment distributions were similar in all three locations. Chlorophyll *a* was the dominant pigment, with zeaxanthin and 19'-hexanoyloxyfucoxanthin the only other predominant pigments. In the chlorophyll maximum samples, small amounts of 19'-butanoyloxyfucoxanthin were also observed. For comparison, the same type pie charts are shown for the surface and chlorophyll maximum pigment data over Northeast Bank (Figure 17).

During the TOPO 1989 survey cruise, Wilkerson and Dugdale obtained nutrient profiles along several sections across the seamount. Only two stations had measurable ammonium, and the Autoanalyzer method showed nitrate to be below detection in the upper 100 m. Nanomolar nitrate measurements, however, showed a consistent nitracline close to the subsurface chlorophyll maximum between 100-120 m, with 12 nM in the mixed layer rising to 1000 nM in the lower part of the

subsurface chlorophyll maximum. The vertical structure across the seamount showed little variation, although flank stations consistently had measurable nanomolar levels of nitrate throughout the euphotic zone. Euphotic zone nitrate along the northwest to southeast transect across Fieberling (Figure 18) showed a trend in surface nitrate concentrations and wavelike patterns in the nitracline above the summit. Whether or not these distributions are due to the presence of the seamount is unclear, and how productivity responds to the patterns remains to be studied.

Interestingly, the phytoplankton seemed to respond to these small (nanomolar) changes in nitrate. At least the phytoplankton pigments covaried with the nanomolar nitrate distributions. Cross-sections of the phytoplankton pigment distributions along the same transect for nanomolar nitrate are given in Figures 19-24. In these figures contour diagrams of the major phytoplankton pigments are displayed along a the same transect from the northwest to the southeast as shown in Figure 18. This transect was conducted on September 18-19, 1989. The stations occupied on this transect (from the northeast) were 31, 32, 33, 34, 35, 36, 37, 38, and 40. Station 30 was occupied over the summit immediately before the transect was begun. The outer stations (31, 32, 38, 40) are in 4000 m water depth, while the inner stations (30, 34, 35, 36) are in water depths less than 900 m. As with the nanomolar nutrients, the highest subsurface pigment levels were found to the west of the seamount. Whether these nanomolar levels of nitrate can have a significant impact upon primary production and pigment variations in the region remains to be determined.

**TOPO 90 Results**

The goal of the phytoplankton pigment work on the TOPO 1990 cruise was to examine the pigment distributions with regard to factors that might influence their distribution, especially zooplankton distribution and current direction. The sampling design of the pigments station on this cruise allowed comparisons to be made of pigment distributrions over and away from two seamounts. The hypothesis to be tested on this cruise was that if the abundance of vertically migrating zooplankton is reduced over the seamount, affecting the distribution of migrating species, then reduced grazing pressure could result in higher phytoplankton biomass. To assess this potential, several of the CTD-pigment transects were taken along the MOCNESS tow lines. Greene et al. (1994) have described the acoustic measurements made on this cruise and Genin et al. (1994) have described the dynamics of the zooplankton patches that were observed.

On the TOPO 90 water column biology cruise, two long transect lines were conducted over Fieberling and Northeast Bank to cover the same areas as the zooplankton tows. These transect lines (9 CTD staions on each) were both run from southwest to northeast across the summit to follow the current flow at Fieberling. Both data from the TOPO current meter moorings and from satellite-tracked drifters were available to us in real time aboard the vessel. The fluorescence maximum at Fieberling during 1990 was slightly shallower than during 1989. Pigment levels were also lower in 1990, with less than 200 ng/L chlorophyll *a* at the subsurface maximum, compared to ~250 ng/L in 1989. These lower levels probably resulted from lower light levels in 1990 (October vs. September sampling).

Two CTD transect lines were also conducted at Northeast Bank (Figure 10). These lines were run from southeast to northeast, again with the prevailing current. Phytoplankton pigment samples were only collected on the 9-station transect which crosses the summit of Northeast Bank. During both years, fluorescence maxima and pigment levels were lower at Fieberling than at Northeast Bank, where chlorophyll *a* ranged from 400 to 700 ng/L in the subsurface maximum. Also, there was a marked difference in the pigment levels (higher) and shape of the fluorescence maxima (more peaked) over the summit of Northeast Bank compared to distributions in surrounding waters. These distinct phytoplankton biomass changes over Northeast Bank may indicate that seamount-induced processes have a strong influence on plankton distributions at seamounts with shallow summits.

An interesting observation was made from the fluorescence profiles from the TOPO 90 cruise. We had noted earlier that the shape (peakedness) of the fluorescence was different above the seamount and at the distant stations. This difference was observed again on the 1990 cruise. Figure 25 shows the vertical fluorescence profiles from two stations: Station 30 over Fieberling and Station 28 far away from the summit (southwest in 4000 m water depth). The fluorescence maximum peak is lower over the summit. The profiles are very similar above and below the maximum region. The two profiles are so similar, it appears that part of the profile has simply been removed.

A similar relationship was observed over Northeast Bank, where the difference is even more pronounced (Figure 26), but the effect is opposite. Higher biomass was observed over the seamount at the chlorophyll maximum, with

slightly lower fluorescence at deeper depths. The fluorescence profiles of these two stations (Station 47 - Northeast summit; Station 48 - 17 km to the west) are almost identical shallower than 25 m and deeper than 125 m. The shallower Northeast Bank is in more productive waters with chlorophyll a levels almost twice the levels over Fieberling Guyot. The comments below only apply to Fieberling Guyot, which is in more oligotrophic waters.

Differences in fluorescence profiles and plankton biomass were observed alos on the TOPO 91 cruise where stations over Fieberling Guyot had lower biomass than those far away. Figure 27 shows a comparison of fluorescence profiles from TOPO 91 summit Station 22 (over) and Station 25 (away). These observations of lower biomass over the Fieberling Guyot summit are the opposite of our original predictions. It is possible that the lower chlorophyll biomass over Fieberling's summit is caused by the changes in zooplankton biomass that have been reported by Green et al. (1994) and Genin et al. (1994), yet lower zooplankton biomass should lead to lower zooplankton grazing and perhaps result in higher (not lower) chlorophyll levels. These two concepts may not be inconsistent.

In the oligotrophic waters of the central Pacific Ocean, the size of the phytoplankton are typically small. They are probably too small to be grazed by large, migrating zooplankton that would be revealed by acoustic sensors. The major phytoplankton grazers are likely to be microzooplankton that do not migrate vertically. If the large, migrating zooplankton are indeed reduced in number above Pacific Ocean seamounts there would be fewer organisms preying upon the microzooplankton that are consuming the phytoplankton. With a reduced

predation from macrozooplankton, the number of microzooplankton would increase and increase the grazing pressure upon the resident phytoplankton population. This increased phytoplankton grazing by microzooplankton would lower the phytoplankton biomass levels over the seamount where the zooplankton patches are most pronounced. This idea is only a theory at present, but it represents a plausible explanation of the lower phytoplankton biomass levels observed over the Pacific Ocean seamounts during the TOPO cruises. While our lower biomass observations were the exact opposite of what we had originally predicted, they reveal the complex interactions of various trophic levels that cause seamount summits to become biological oases in otherwise barren waters.

Table 6. Summary of data collected on each of the TOPO water column biology cruises.

| Description | TOPO 89 | TOPO 90 | TOPO 91 |
|---|---|---|---|
| Vessel | R/V New Horizon | R/V New Horizon | R/V Thompson |
| Duration (days) | 16 | 20 | 19 |
| CTD Stations | 42 | 58 | 58 |
| Pigment Stations | 22 | 48 | 55 |
| Pigment Samples | 240 | 400 | 440 |

Table 7. Mean values for major phytoplankton pigments found during the 1989 TOPO water column biology cruise.

| Phytoplankton Pigments [ng per liter] | **Over Fieberling** Sta. 3, 30, 35 | | **Fieberling Flank** Sta. 5, 7, 9, 12, 14 | | **Fieberling Base** Sta. 4, 6, 8, 11, 13 | |
|---|---|---|---|---|---|---|
| | Surface | Chl Max | Surface | Chl Max | Surface | Chl Max |
| Chlorophyll *a* | 55 | 202 | 68 | 208 | 67 | 215 |
| Chlorophyll *b* | 0 | 81 | 0 | 102 | 0 | 105 |
| Fucoxanthin | 0 | 0 | 3 | 5 | 0 | 6 |
| 19'butfucoxanthn | 2 | 25 | 4 | 36 | 0 | 36 |
| 19'hexfucoxanthn | 11 | 45 | 10 | 48 | 12 | 55 |
| Zeaxanthin | 38 | 40 | 41 | 36 | 47 | 37 |

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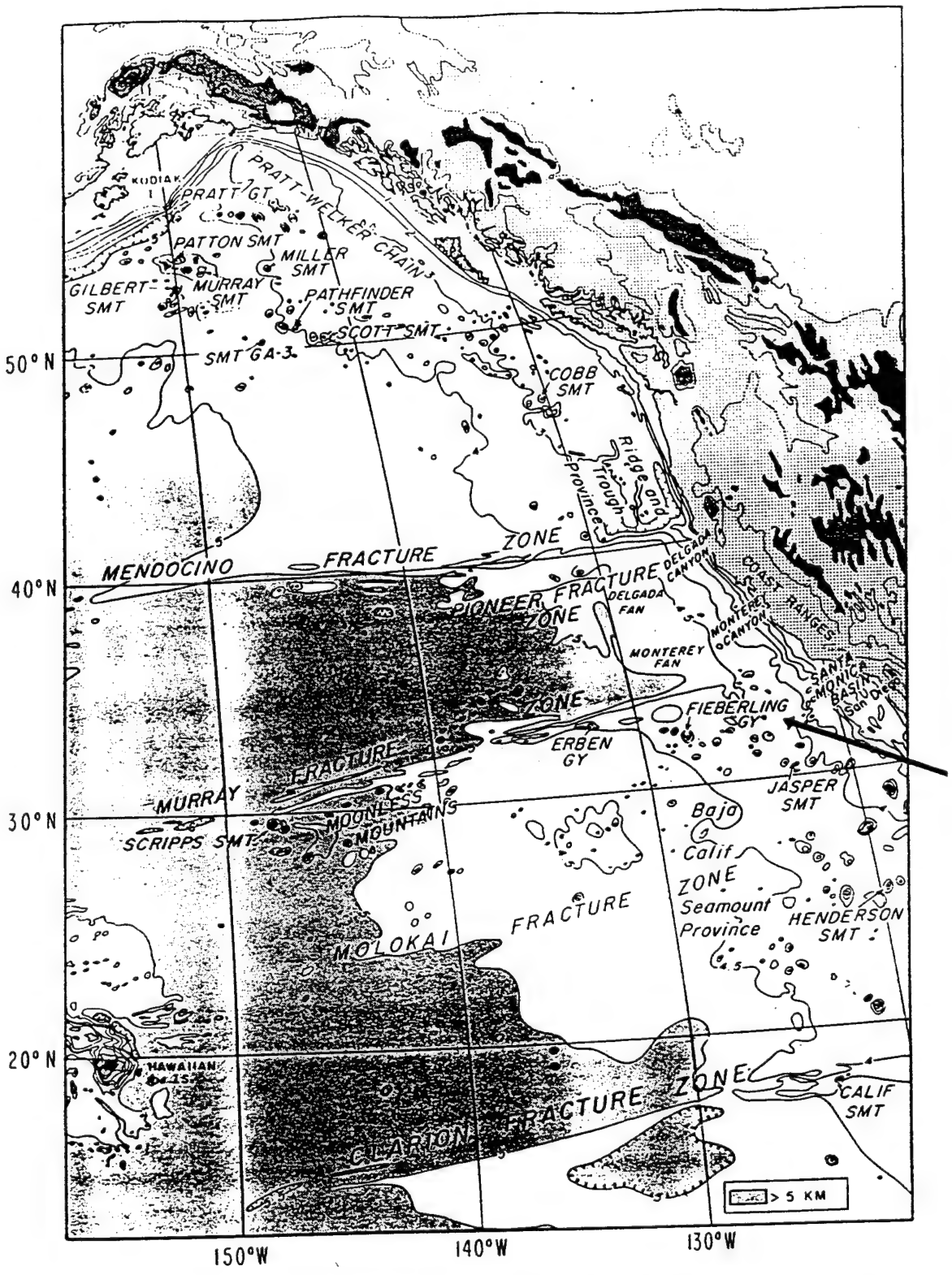



Figure 1. Bathymetry of the Pacific Basin showing the location of Fieberling Guyot at 32° 25'N, 127° 47'W (from Menard, 1964).

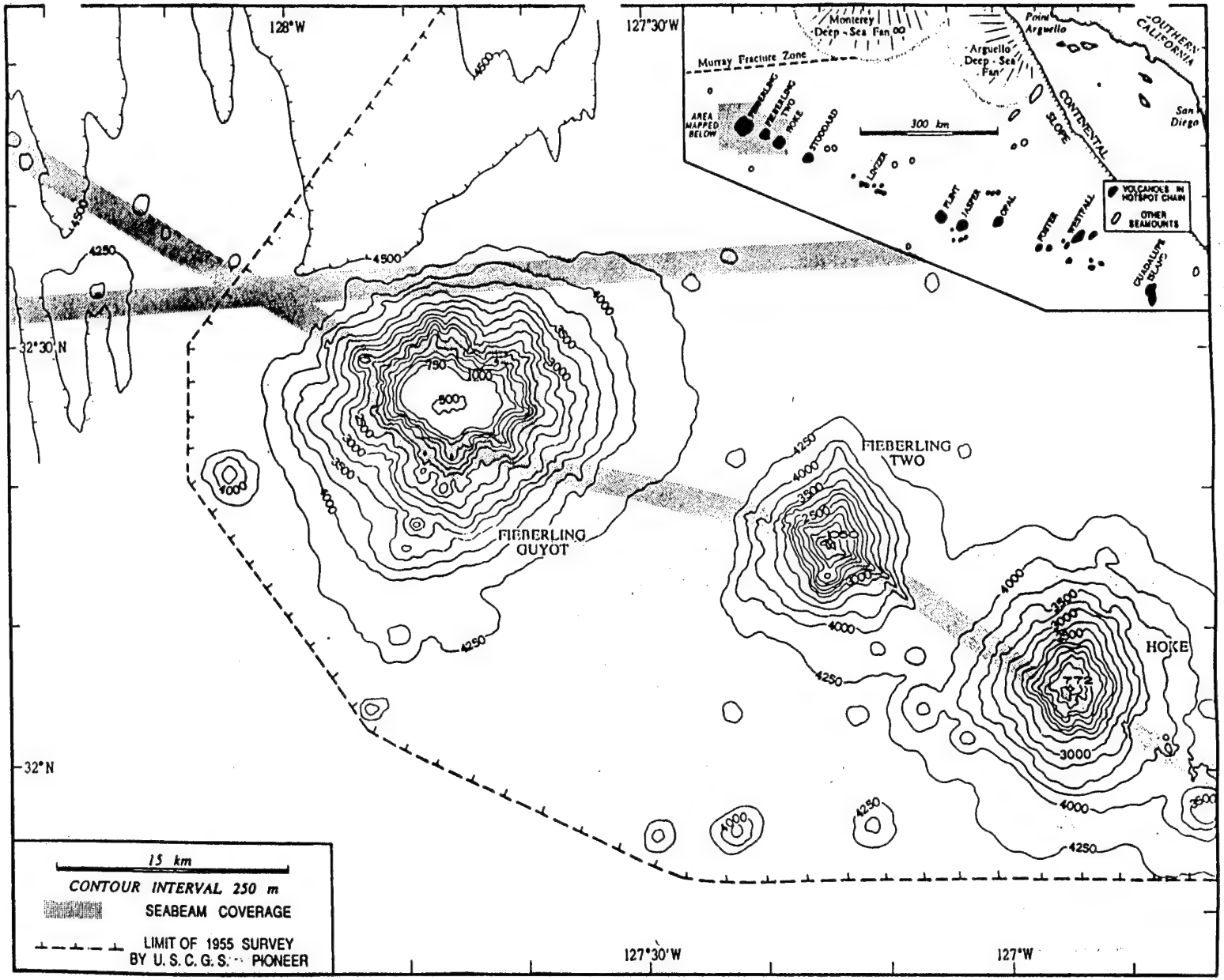



Figure 2. Bathymetric map of the area around Fieberling Guyot.

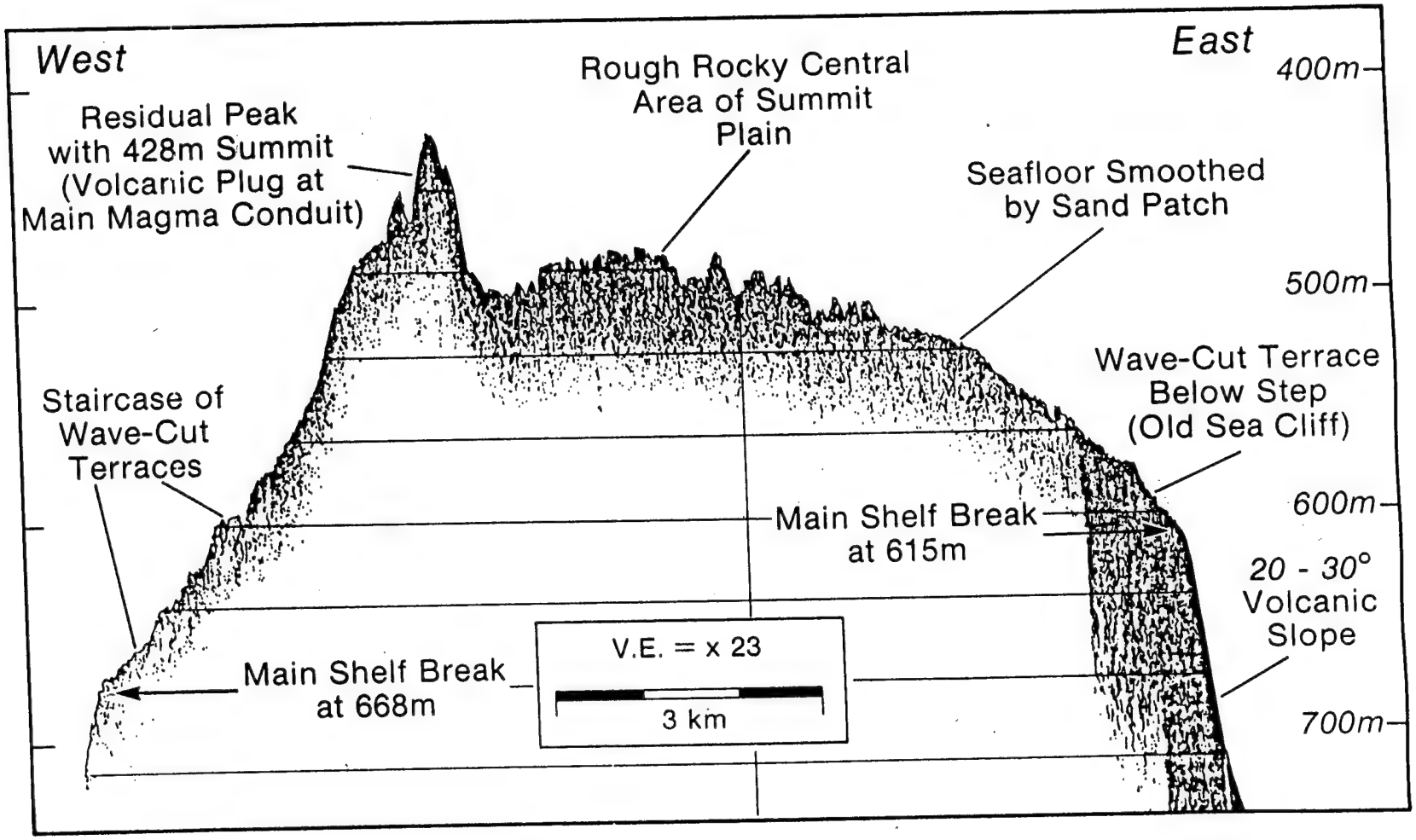



Figure 3. Data from a seismic line from west to east across the summit of Fieberling Guyot.

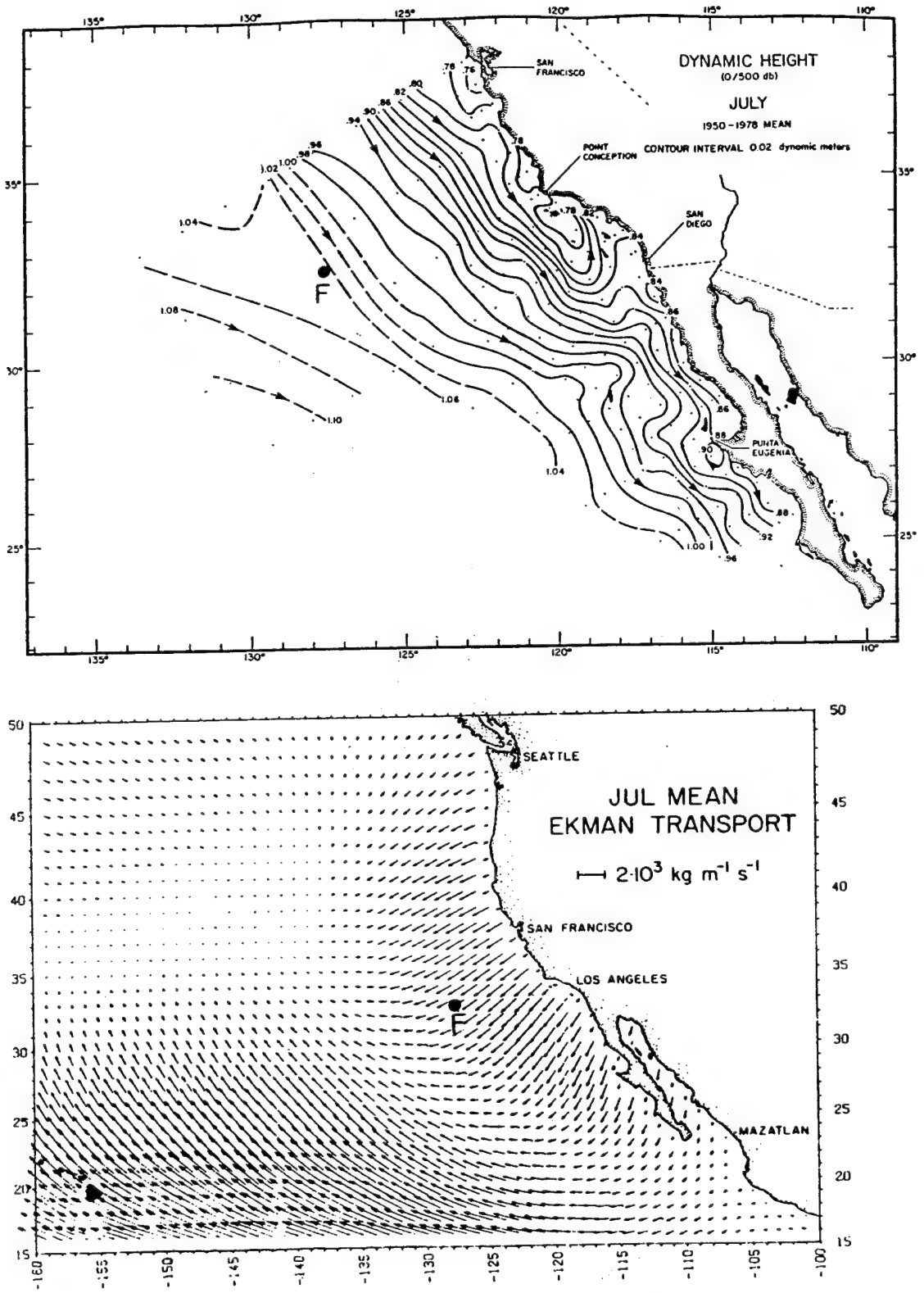



Figure 4. Climatological rendition of (top) the California Current and (bottom) the long-term mean Ekman transport for the month of July. Fieberling is denoted by the letter F. (from Roden, 1991).

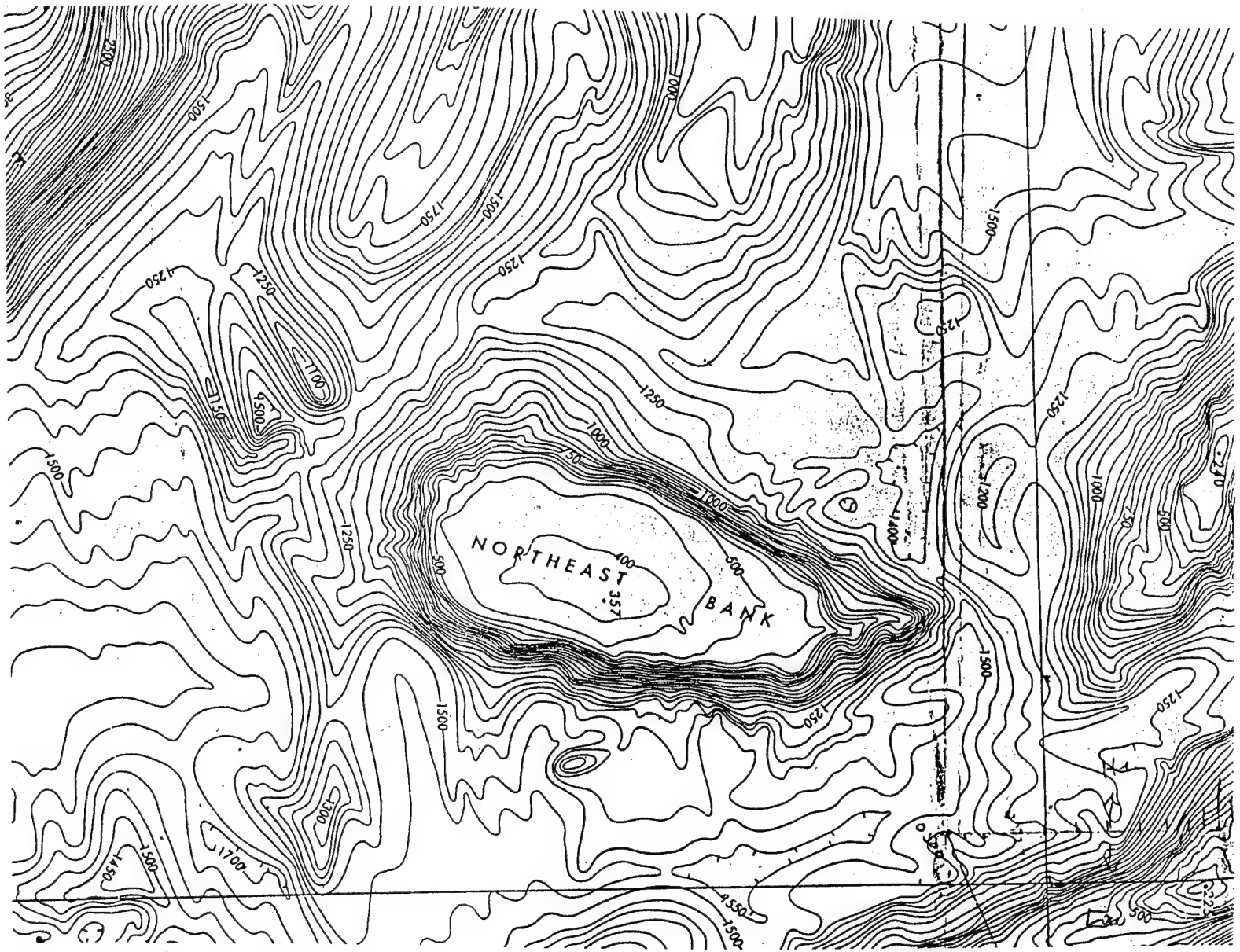



Figure 5. Bathymetric map of the area around Northeast Bank.

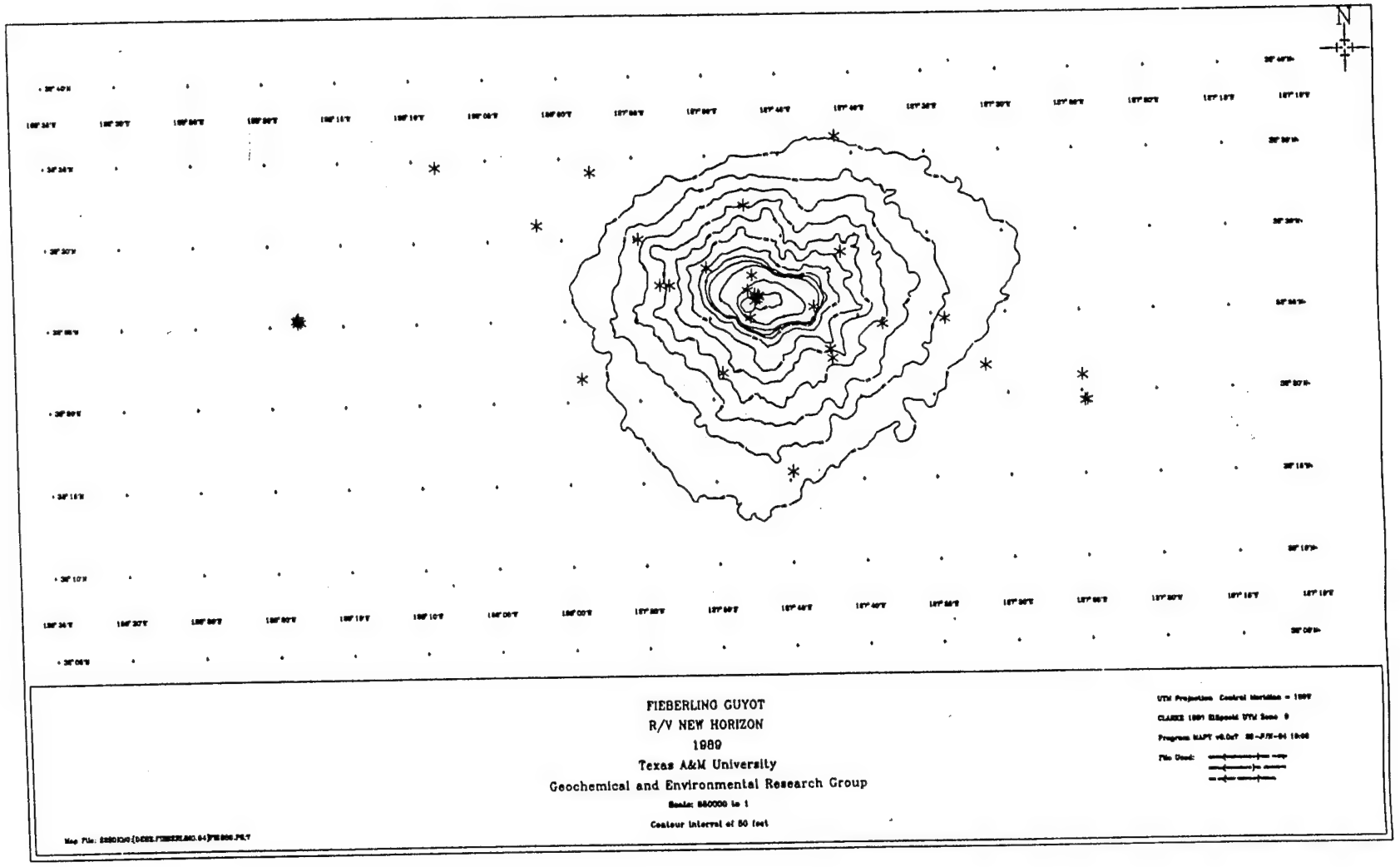



Figure 6. Map of station locations occupied on and near Fieberling Guyot during TOPO 89

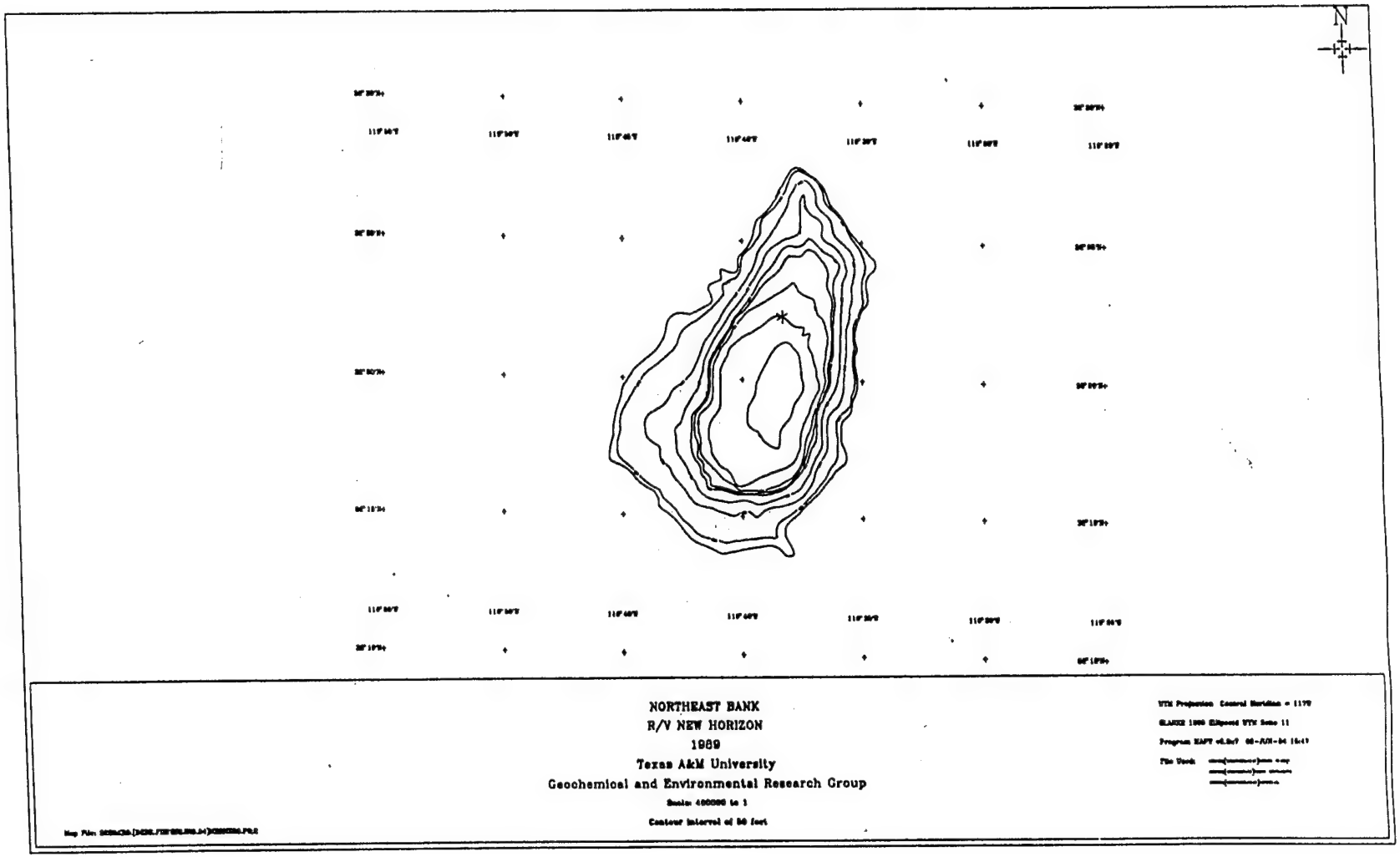



Figure 7. Map of station location occupied over Northeast Bank during TOPO 89.

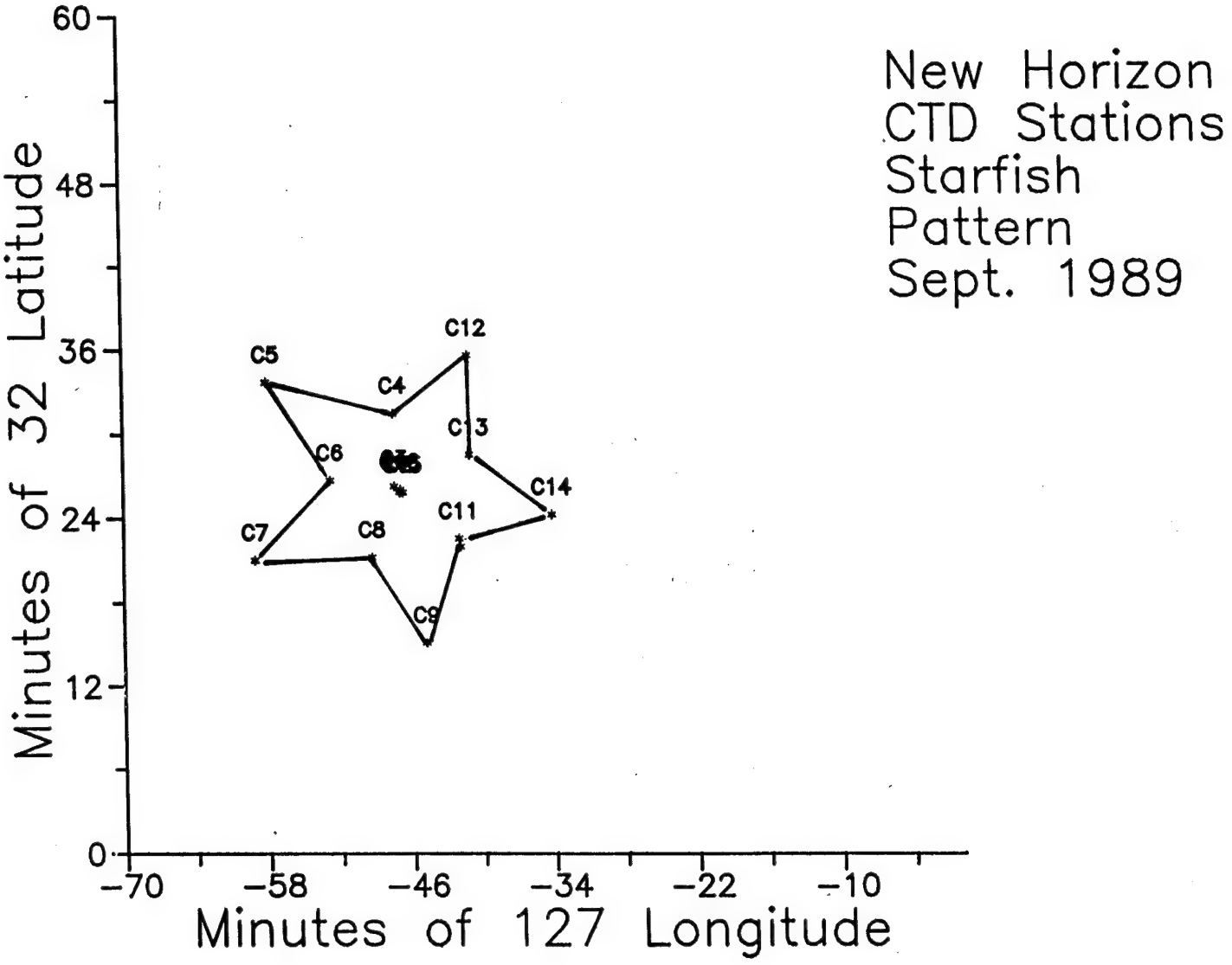



Figure 8. Schematic diagram of the starfish pattern station occupied near Fieberling Guyot during the early stages of the TOPO 89 cruise.

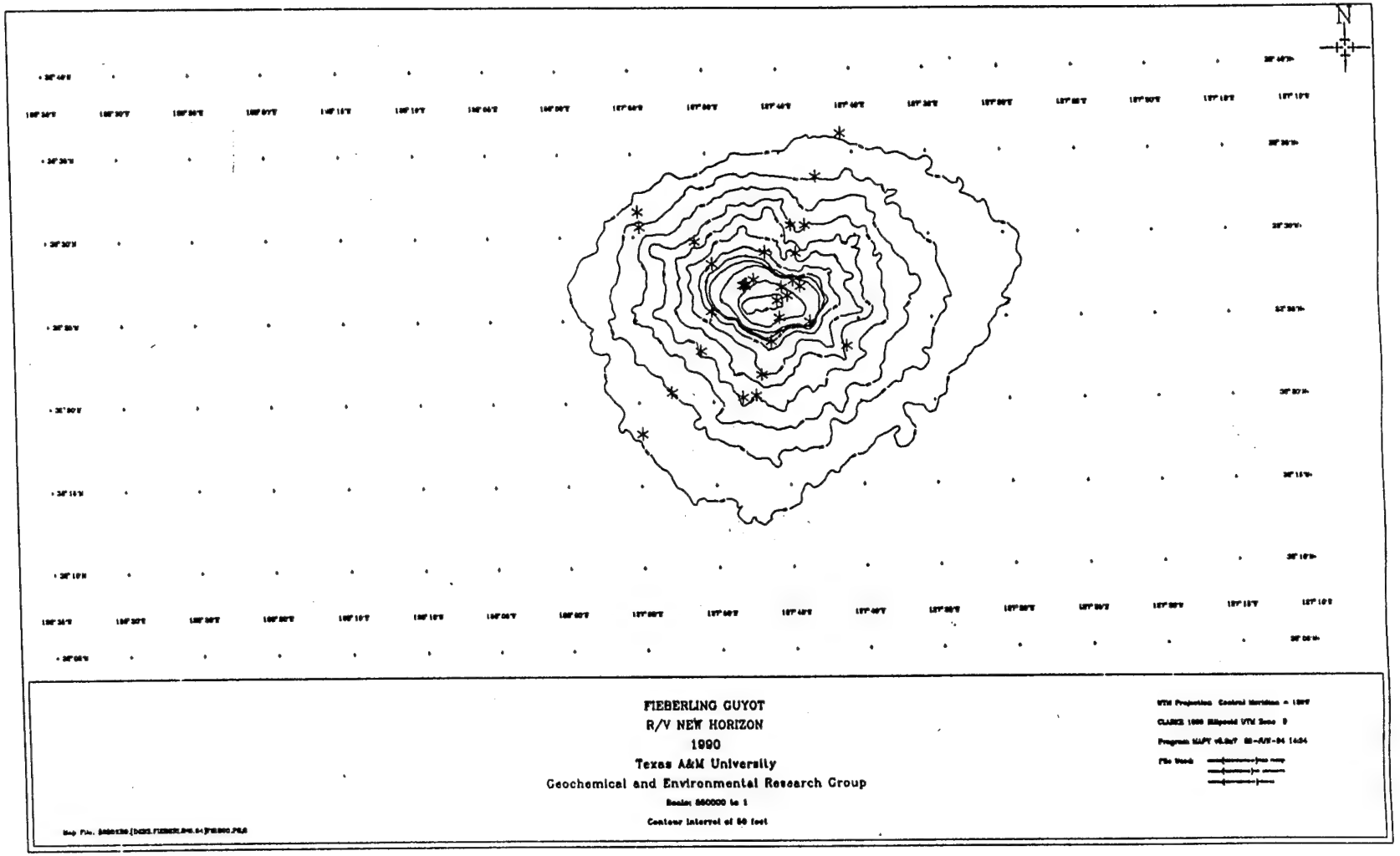



Figure 9. Map of station locations occupied on and near Fieberling Guyot during TOPO 90.

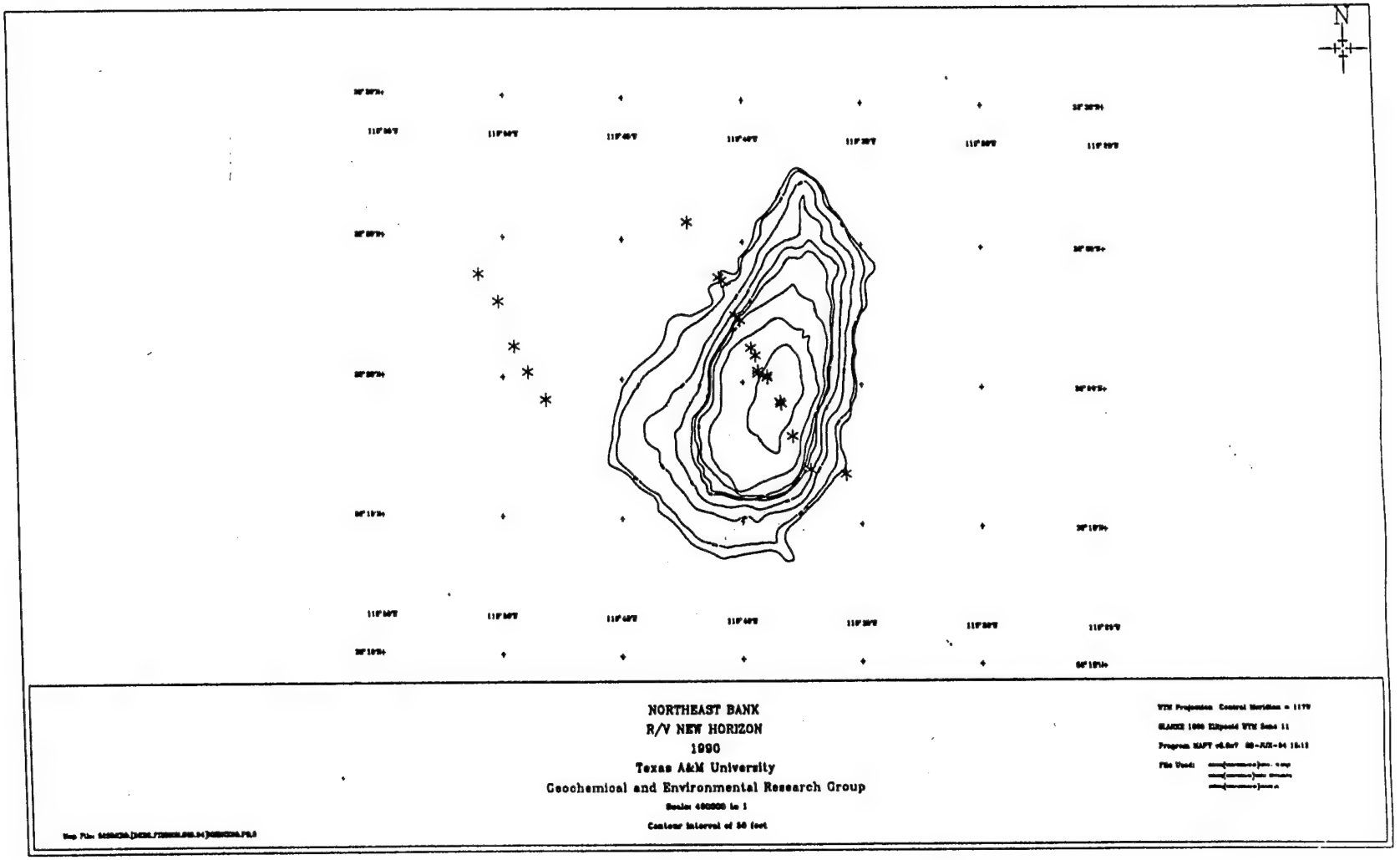



Figure 10. Map of station locations occupied on and near Northeast Bank during TOPO 90.

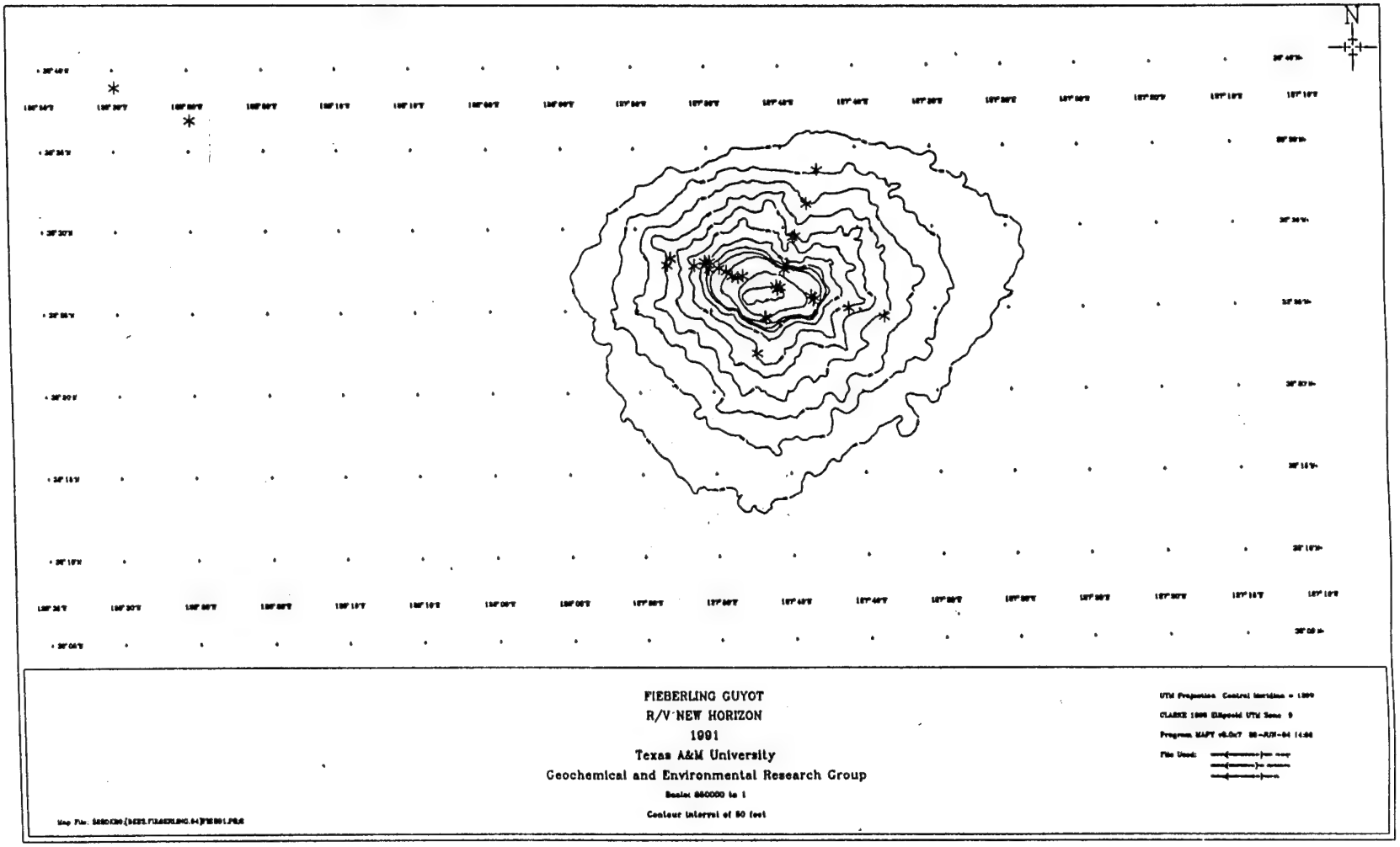



Figure 11. Map of station locations occupied on and near Fieberling Guyot during TOPO 91.

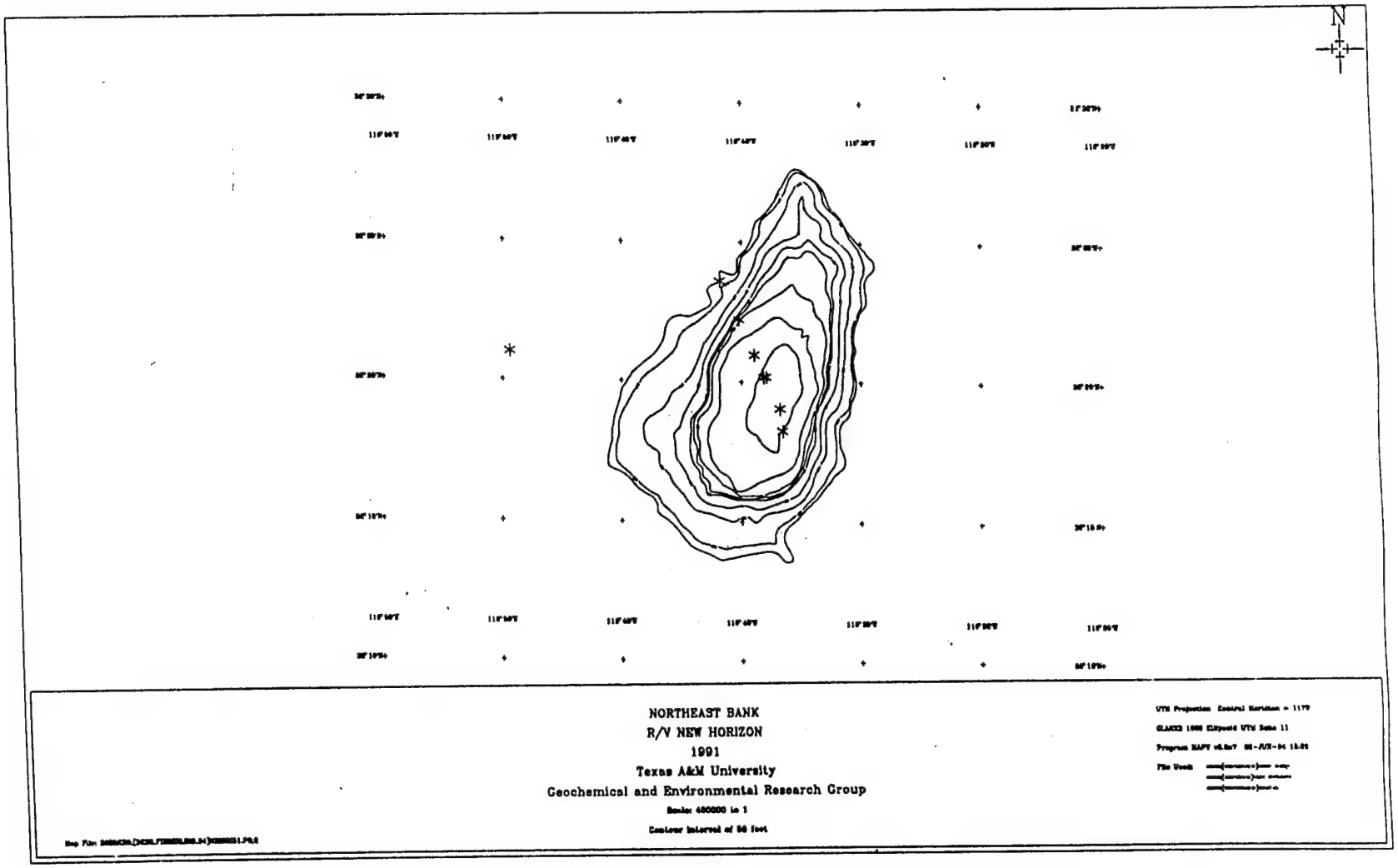



Figure 12. Map of station locations occupied on and near Northeast Bank during TOPO 91.

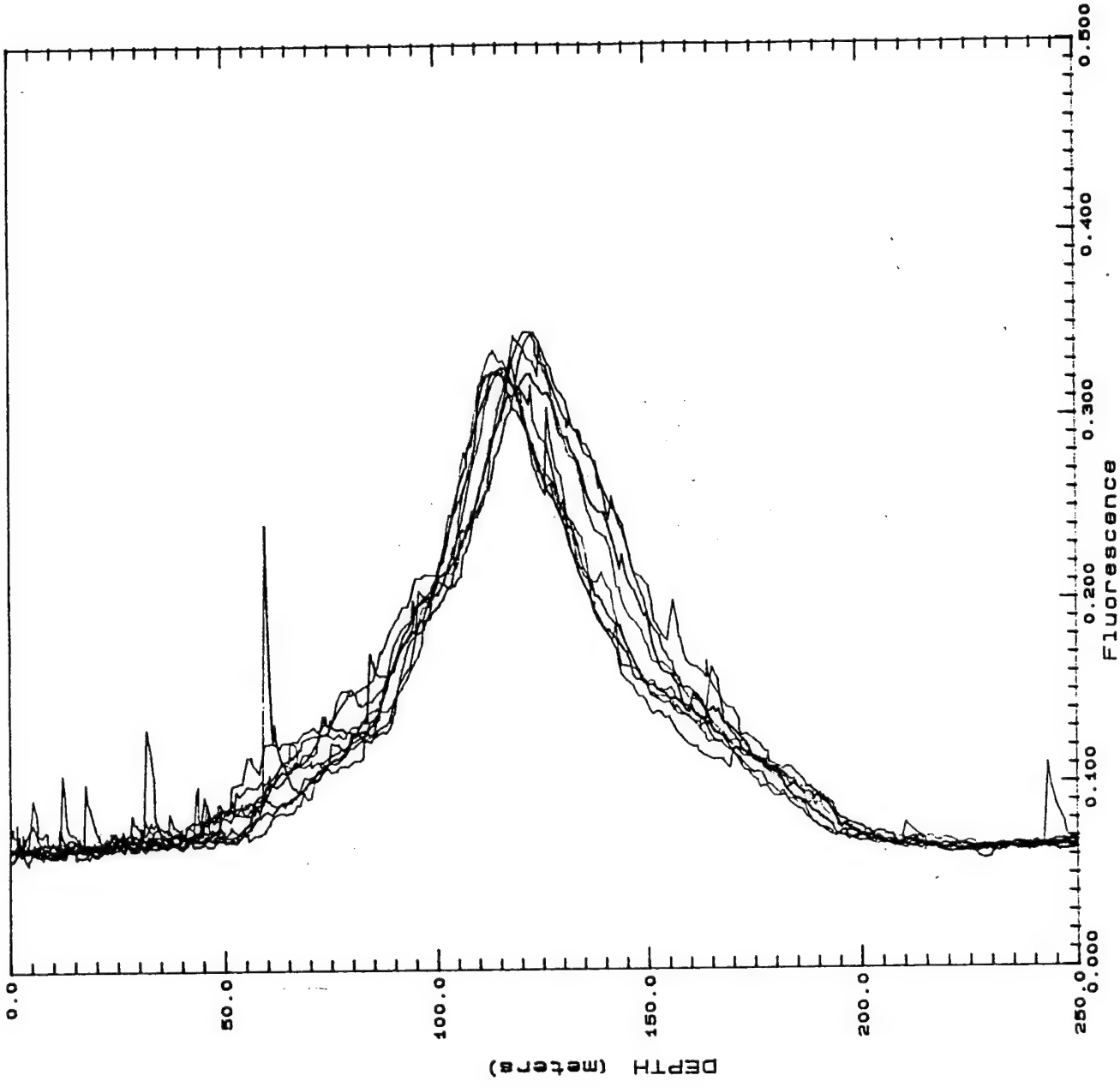



Figure 13. Examples of depth changes in the fluorescence maximum observed during TOPO 89.

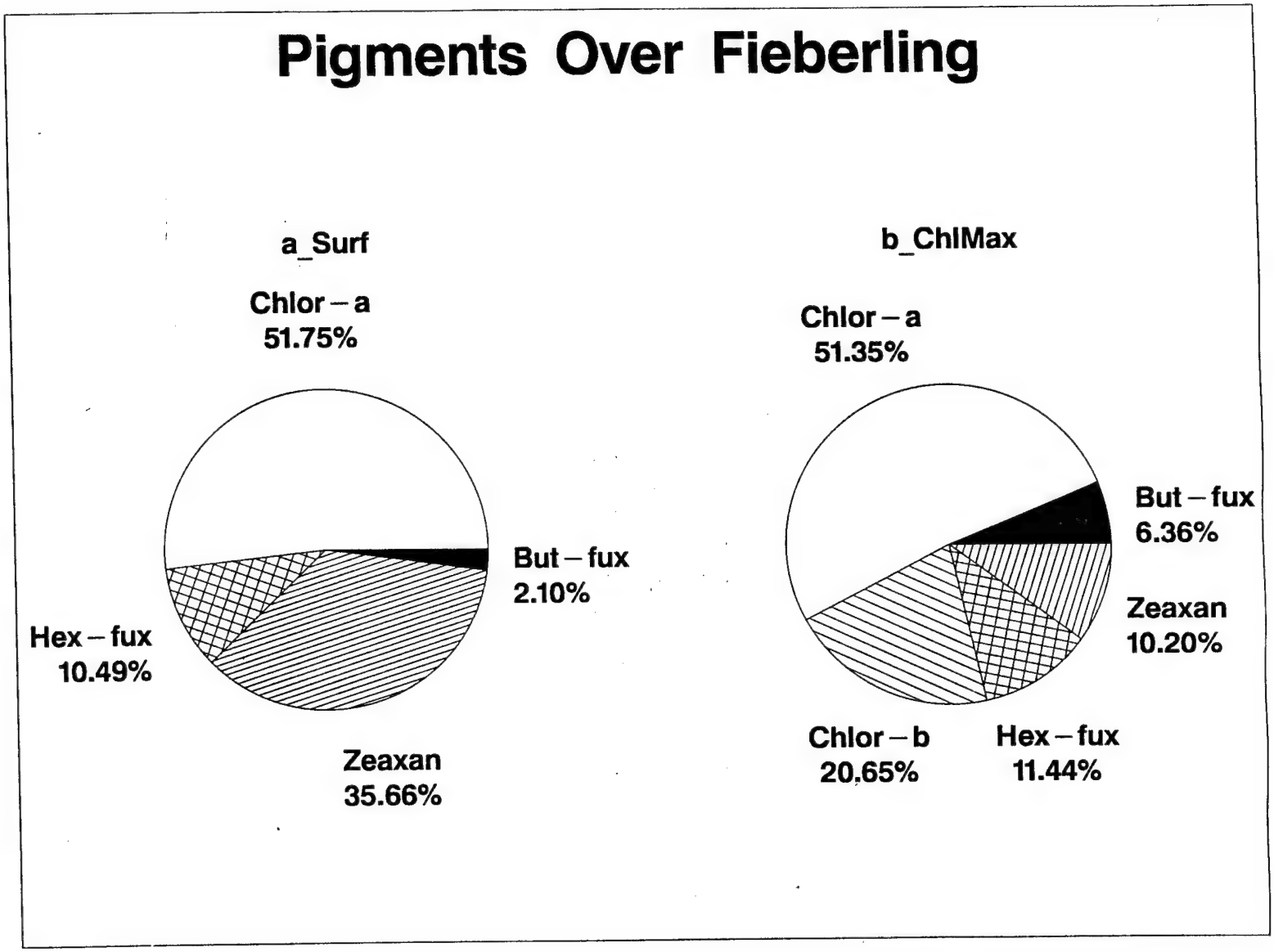



Figure 14. Pie diagram showing the distribution of phytoplankton pigment at the surface and chlorophyll maximum over Fieberling Guyot summit during TOPO 89.

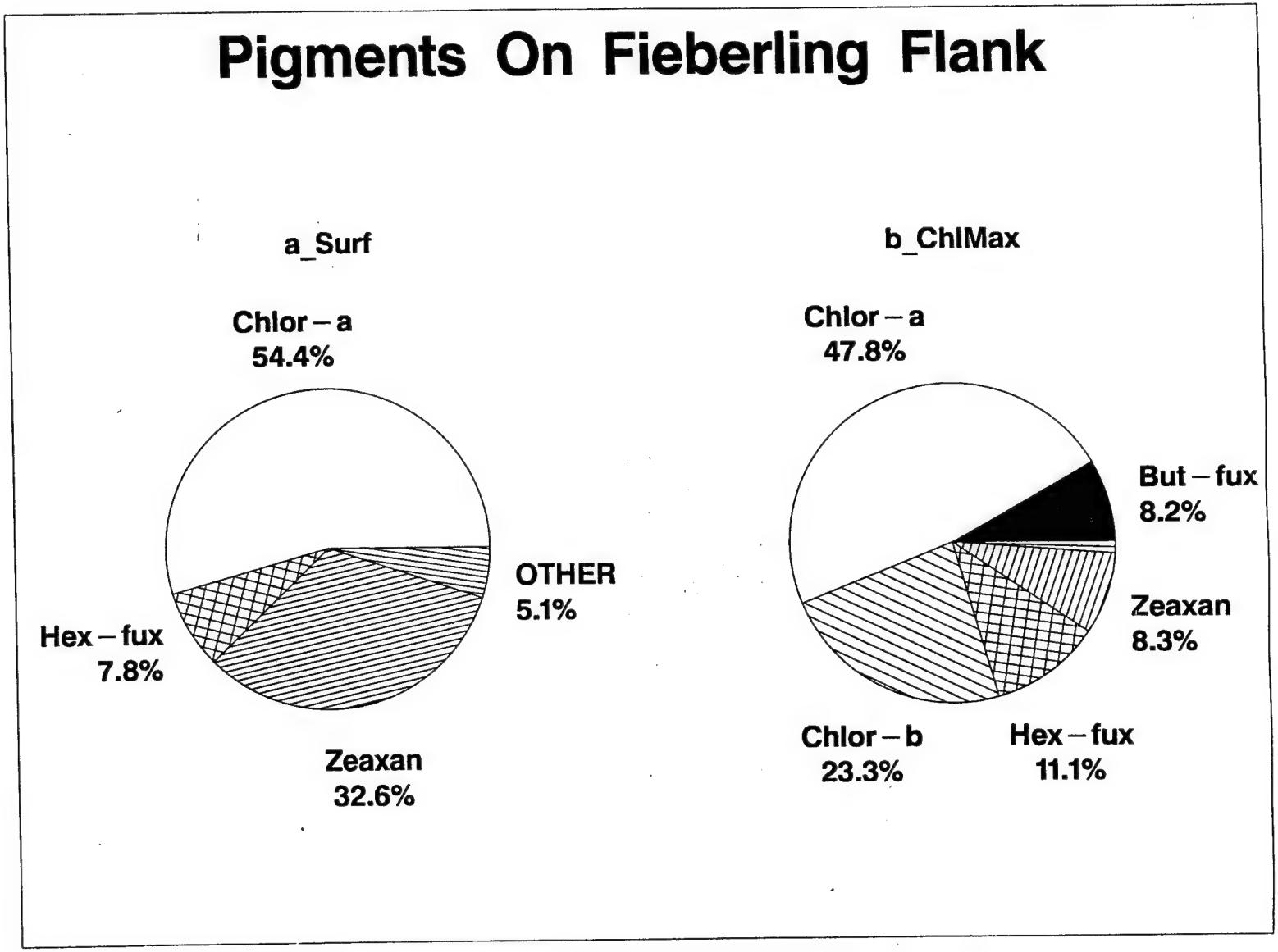



Figure 15. Pie diagram showing the distribution of phytoplankton pigment at the surface and chlorophyll maximum at Fieberling Guyot flank during TOPO 89.

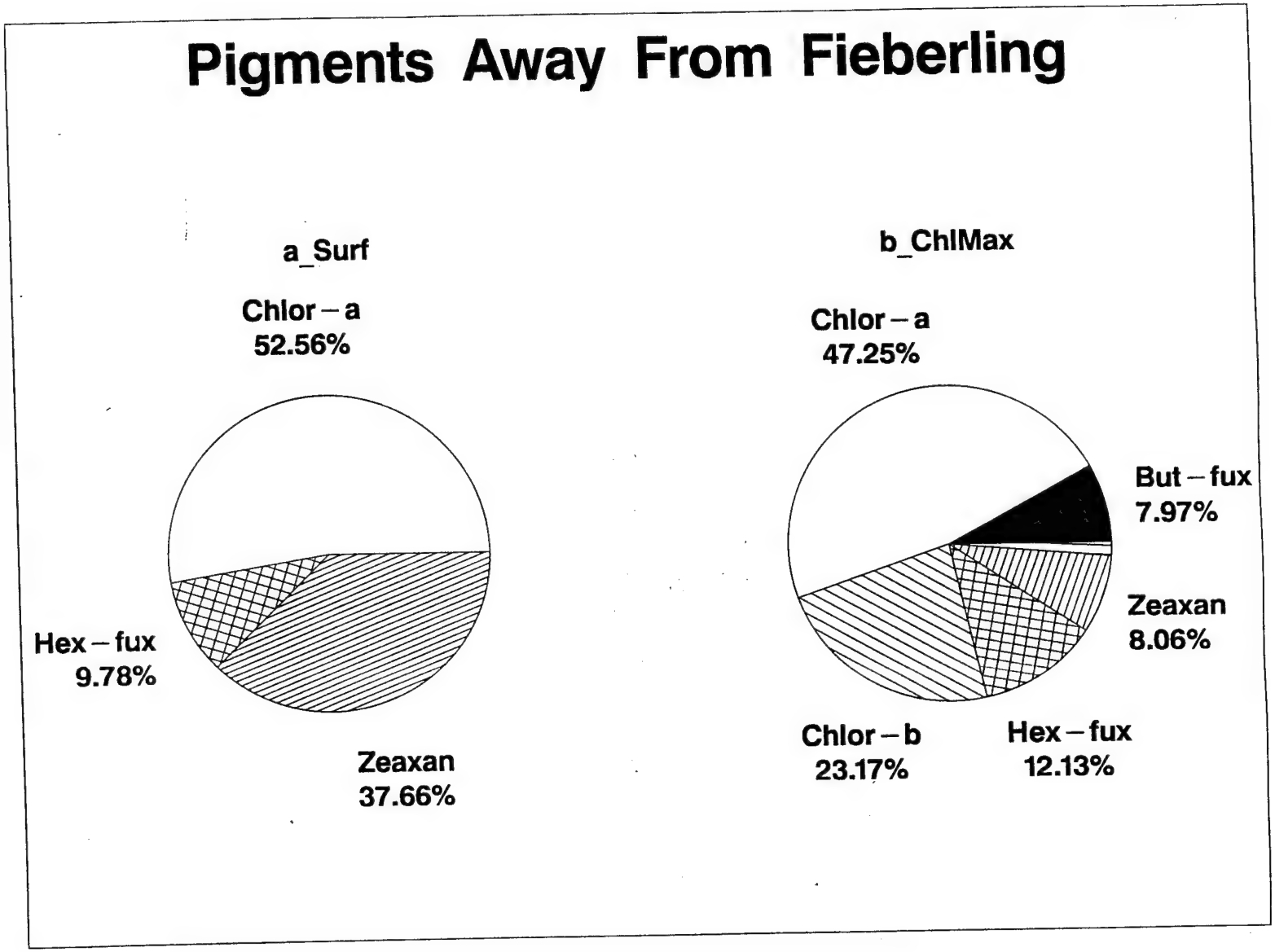



Figure 16. Pie diagram showing the distribution of phytoplankton pigment at the surface and chlorophyll maximum far away from Fieberling Guyot during TOPO 89.

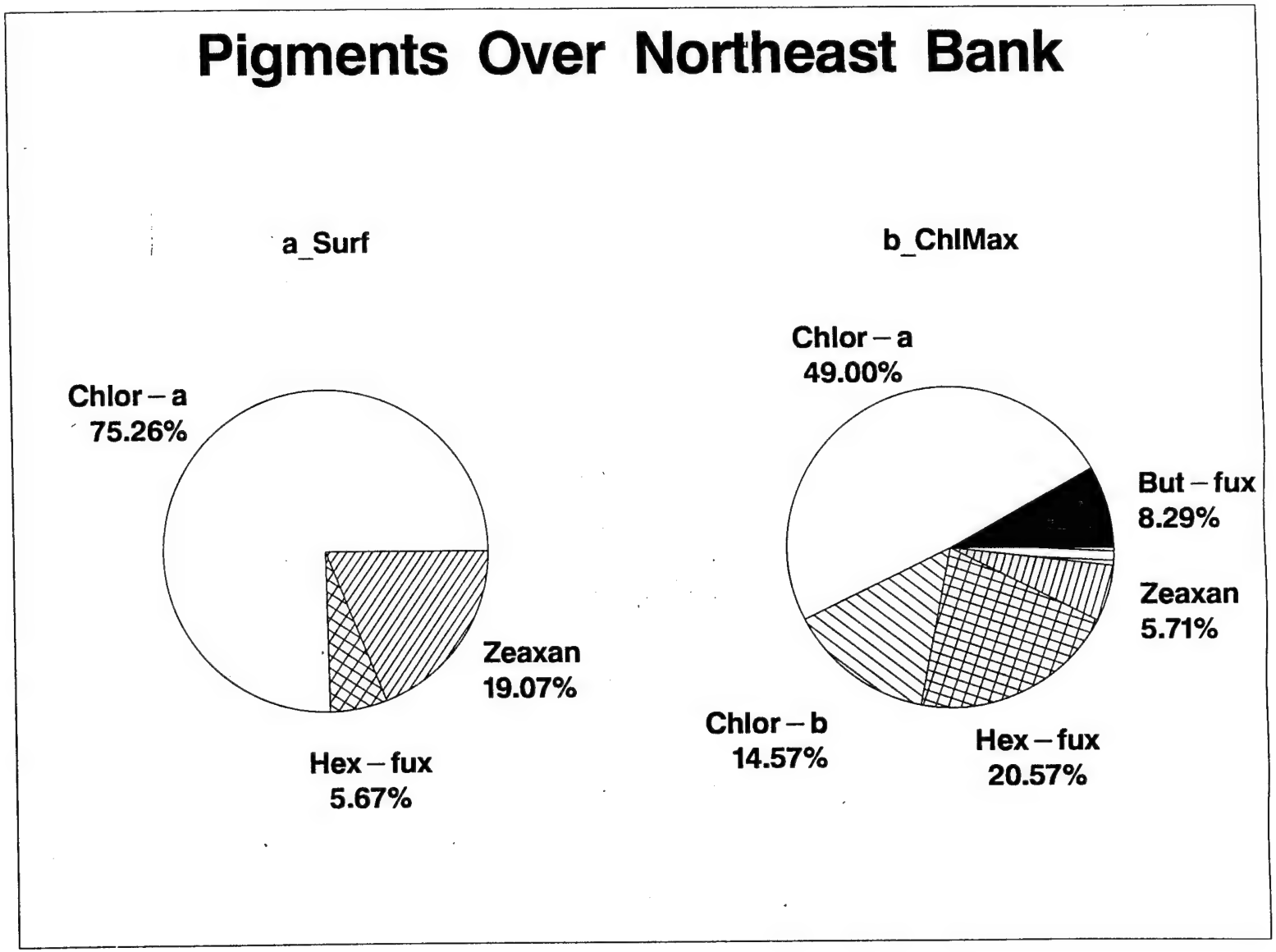



Figure 17. Pie diagram showing the distribution of phytoplankton pigment at the surface and chlorophyll maximum over Northeast Bank summit during TOPO 89.

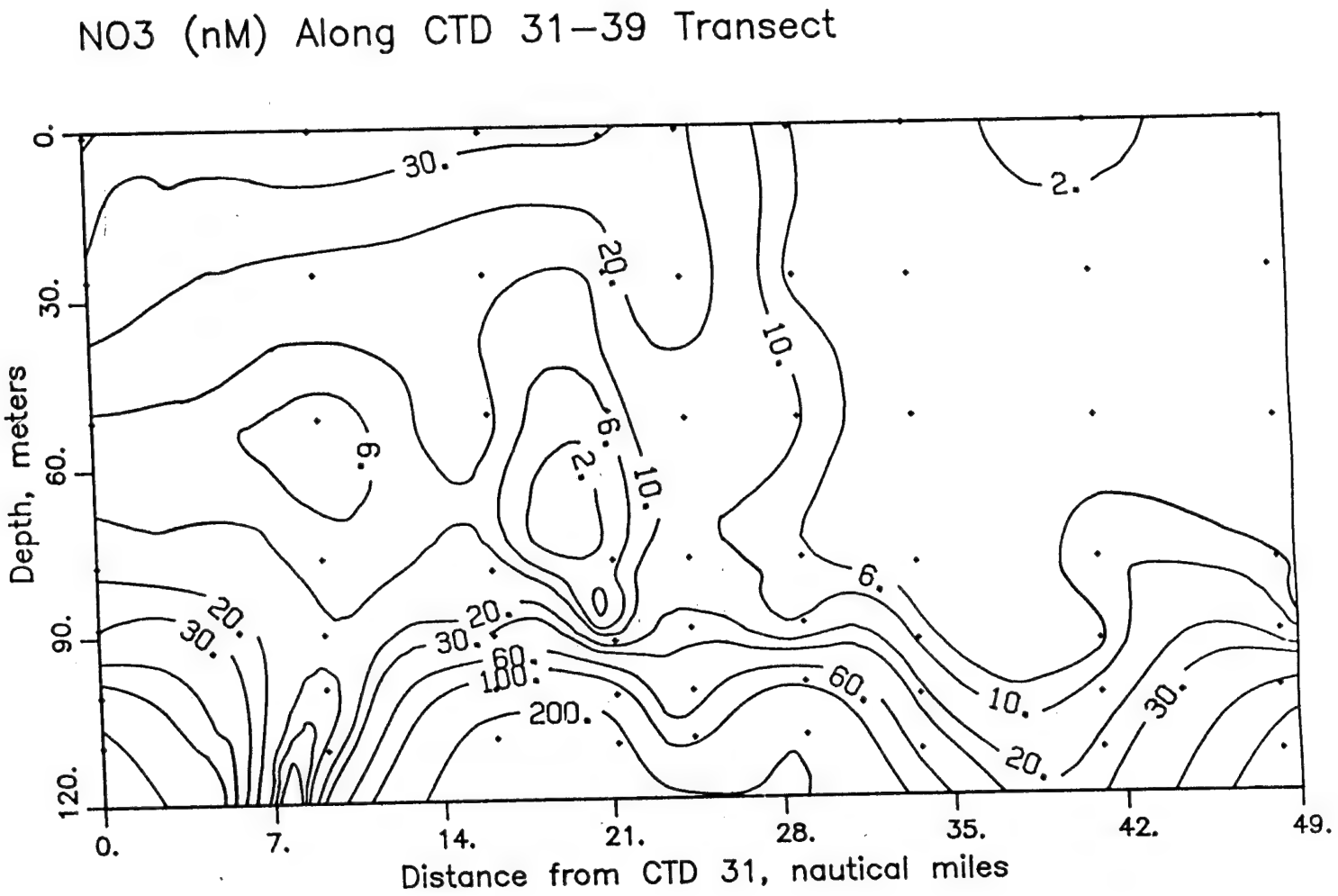



Figure 18. Nitrate distribution (nM) in the euphotic zone along a northwest to southeast transect across Fieberling Guyot during TOPO 89. The seamount summit is located between 21 and 28 nautical miles from CTD 31. This figure was provided by F. Wilkerson.

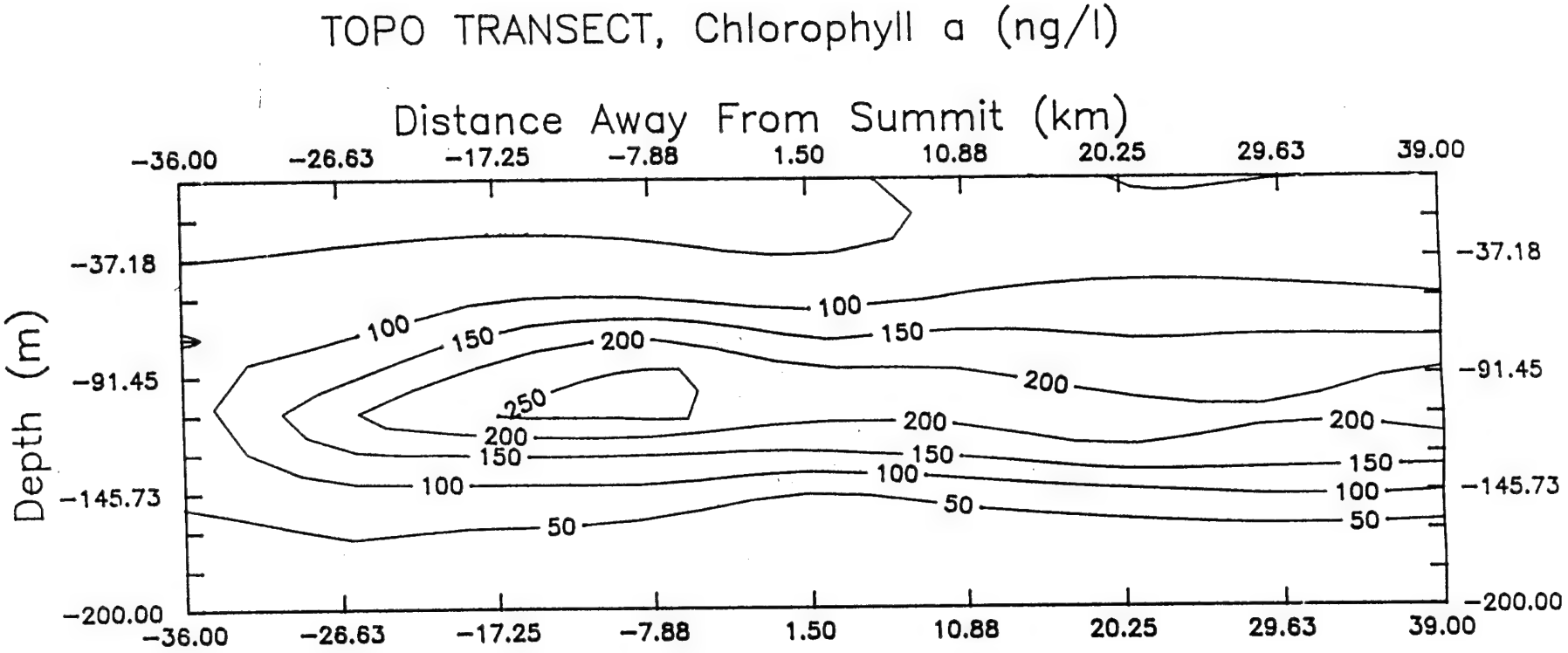



Figure 19. Chlorophyll a distribution (ng/L) for the same transect as shown in Figure 18 across Fieberling Guyot during TOPO 89. Distances (km) are from the summit center.

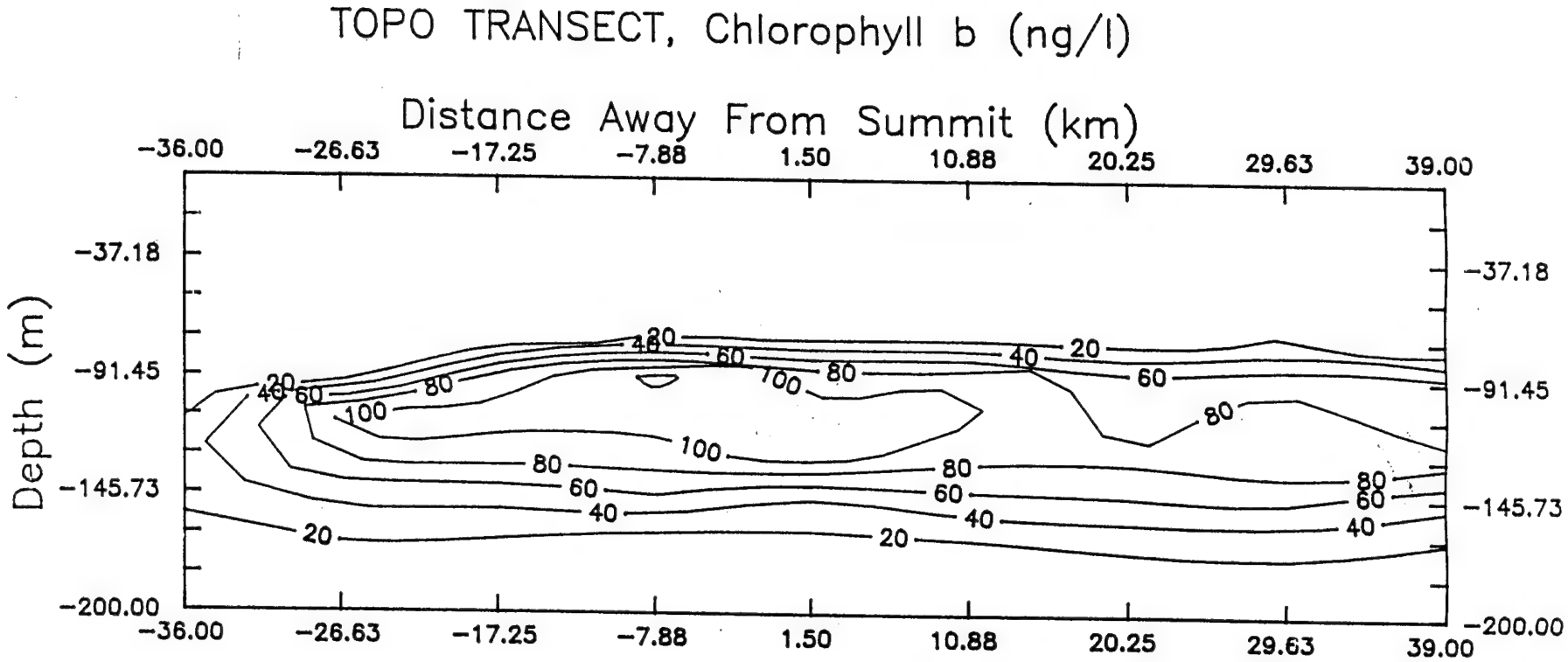



Figure 20. Chlorophyll b distribution (ng/L) for the same transect as shown in Figure 18 across Fieberling Guyot during TOPO 89. Distances (km) are from the summit center.

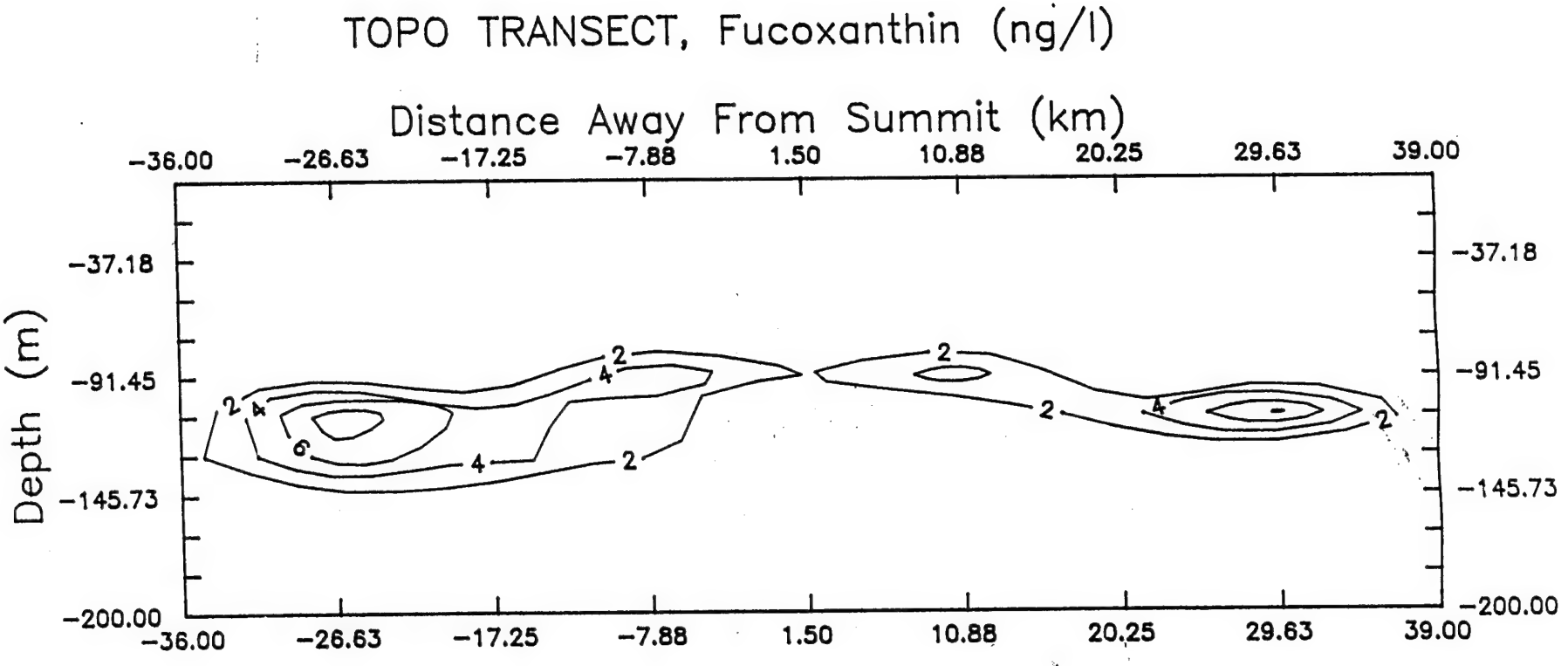



Figure 21. Fucoxanthin distribution (ng/L) for the same transect as shown in Figure 18 across Fieberling Guyot during TOPO 89. Distances (km) are from the summit center.

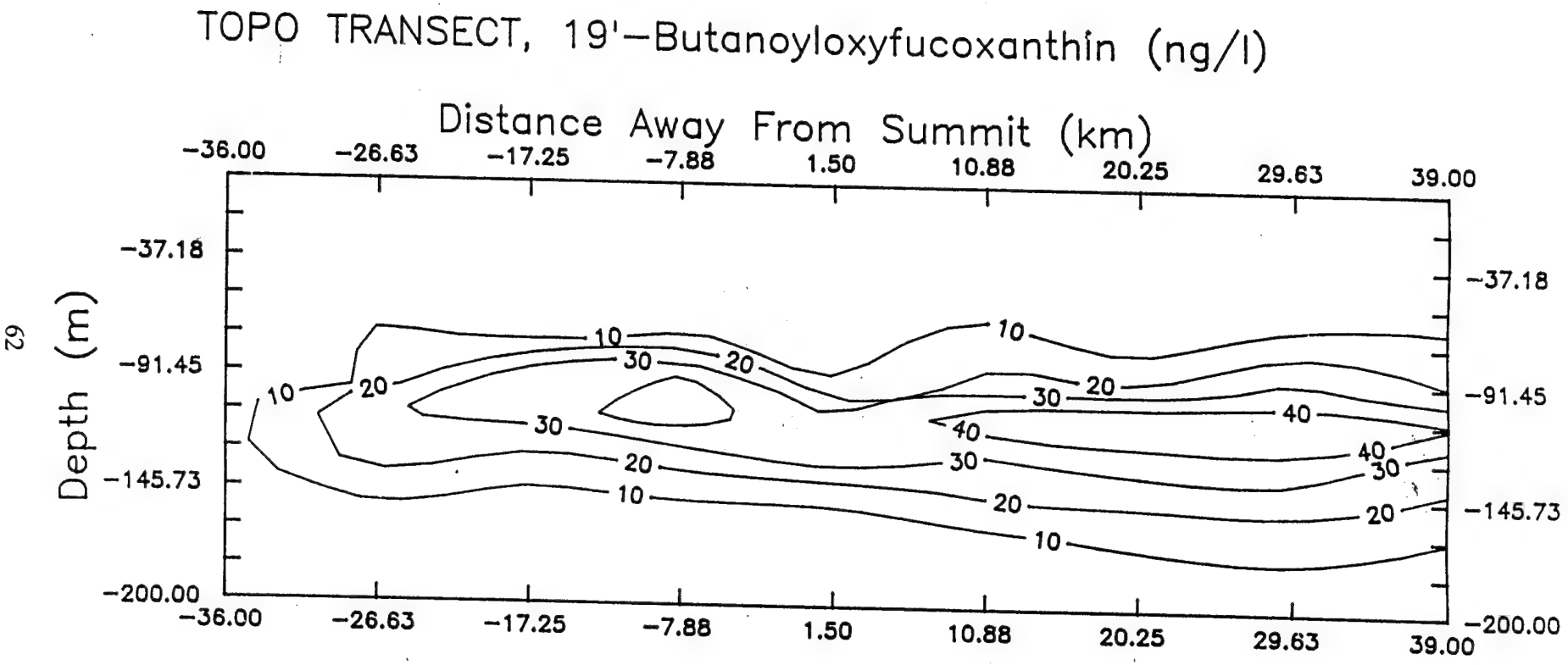



Figure 22. 19'-butanoyloxyfucoxanthin distribution (ng/L) for the same transect as shown in Figure 18 across Fieberling Guyot during TOPO 89. Distances (km) are from the summit center.

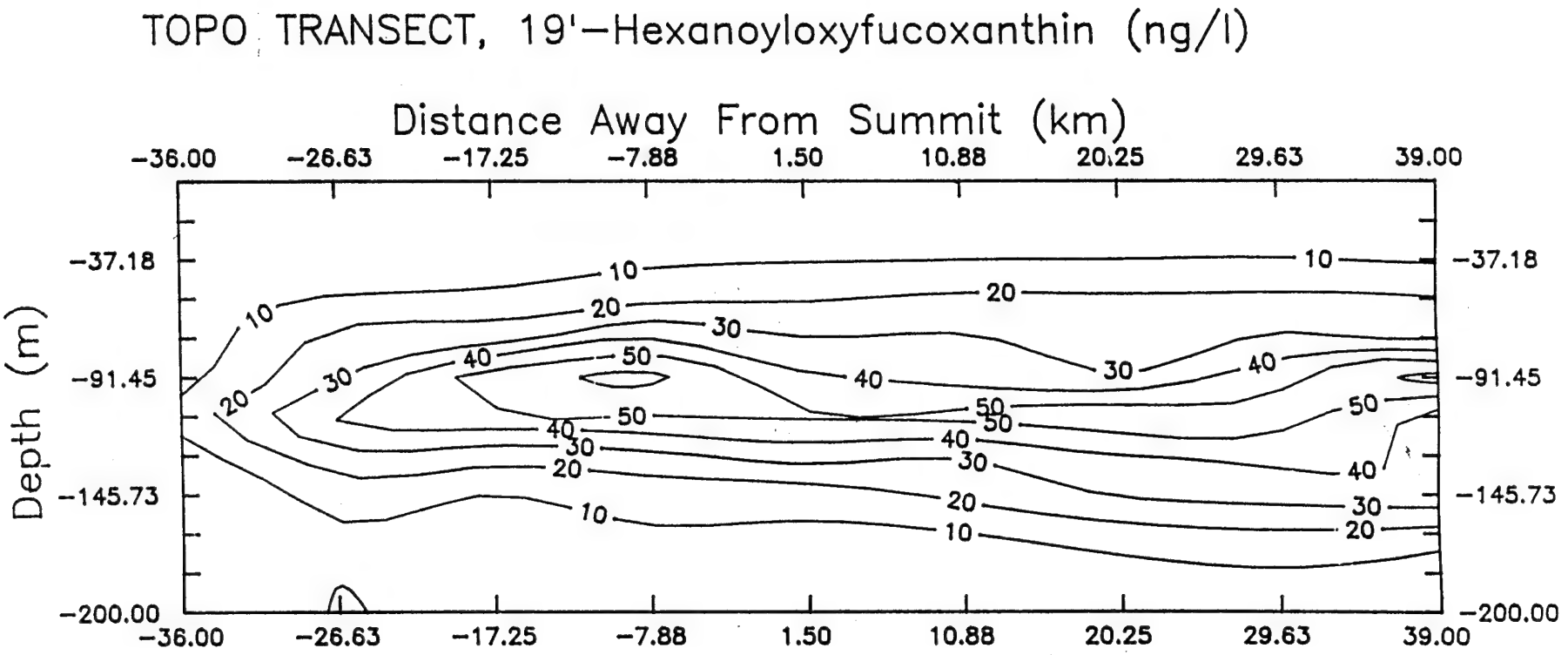



Figure 23. 19'-hexanoyloxyfucoxanthin distribution (ng/L) for the same transect as shown in Figure 18 across Fieberling Guyot during TOPO 89. Distances (km) are from the summit center.

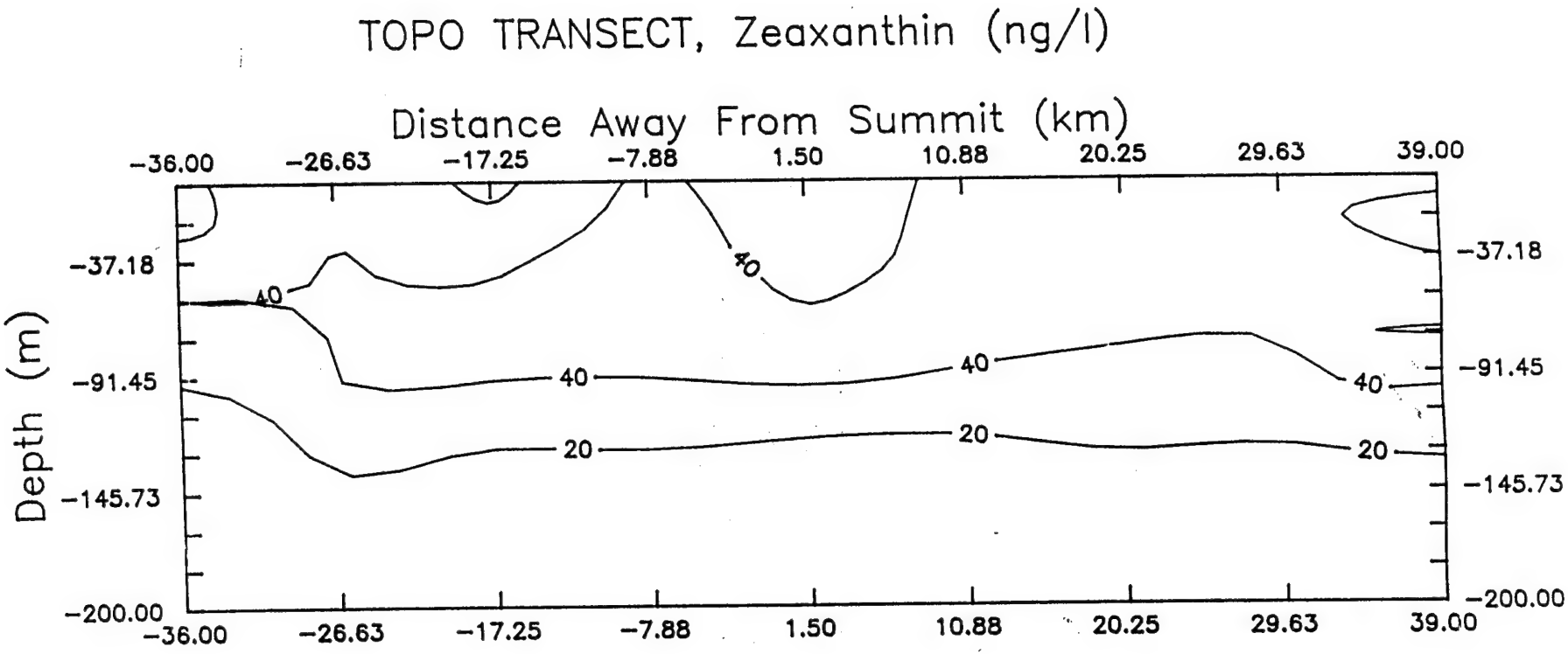



Figure 24. Zeaxanthin distribution (ng/L) for the same transect as shown in Figure 18 across Fieberling Guyot during TOPO 89. Distances (km) are from the summit center.

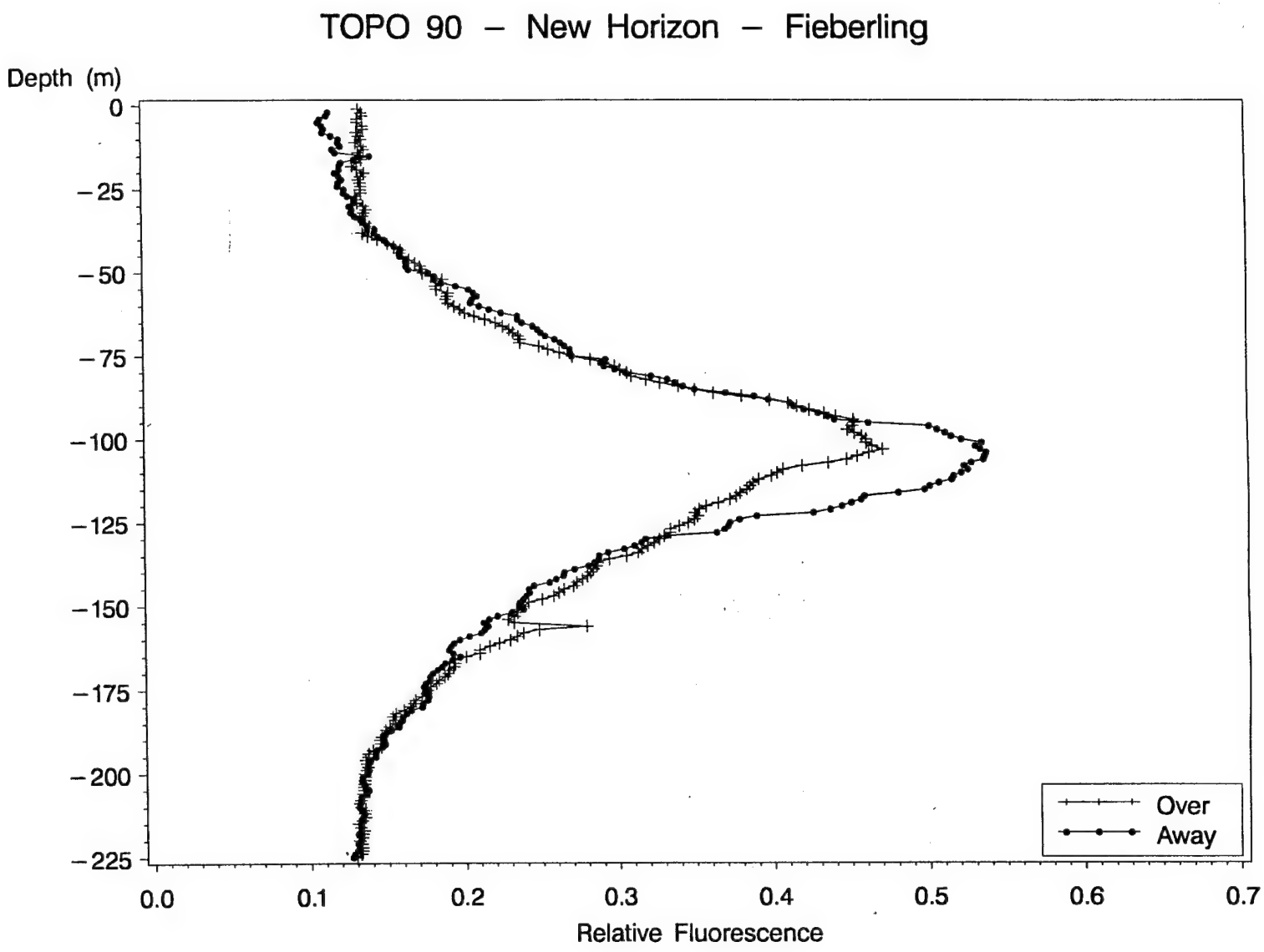



Figure 25. Comparison of vertical profiles of in situ fluorescence over and away from Fieberling Guyot from TOPO 90.

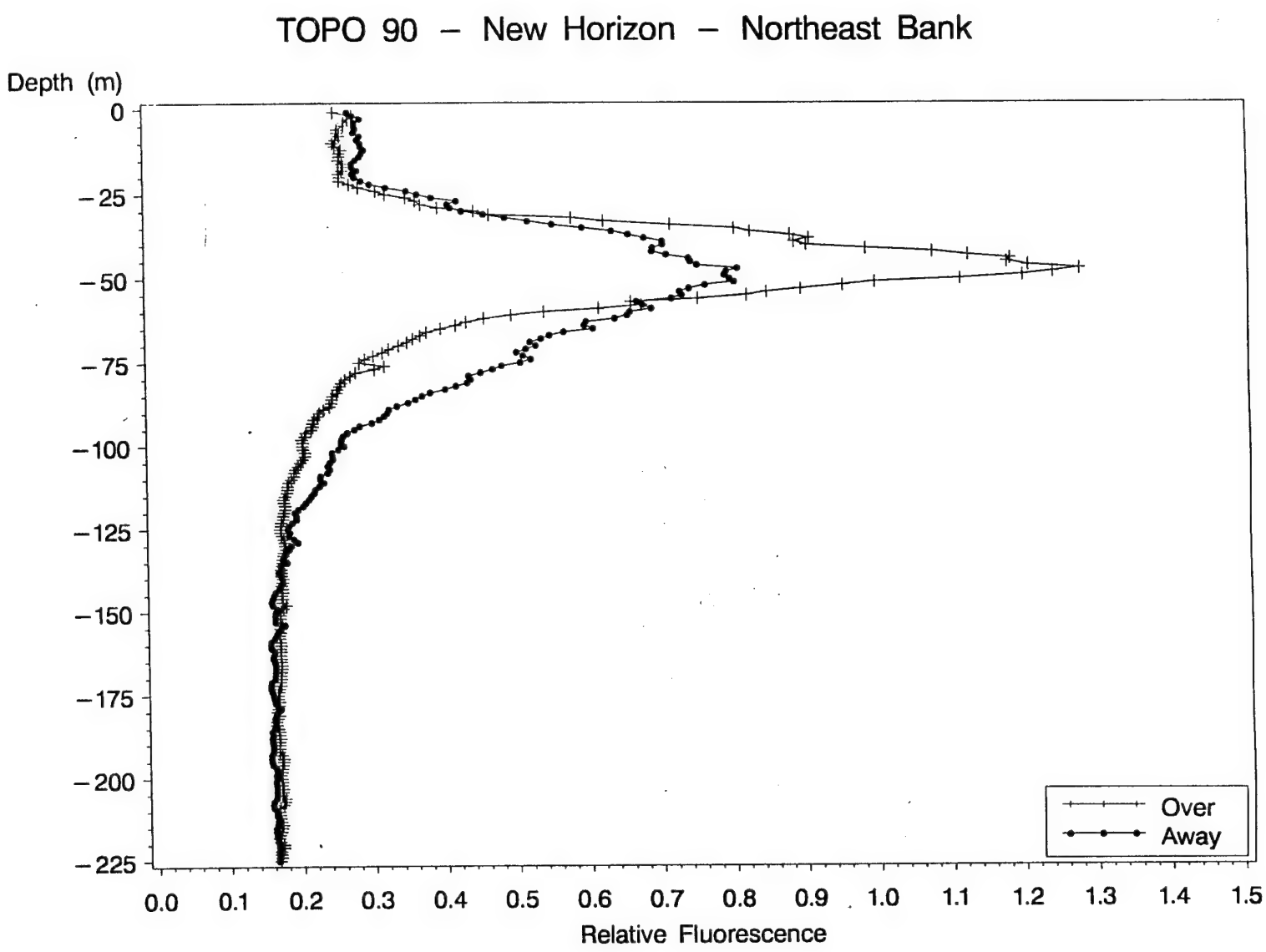



Figure 26. Comparison of vertical profiles of in situ fluorescence over and away from Northeast Bank from TOPO90.

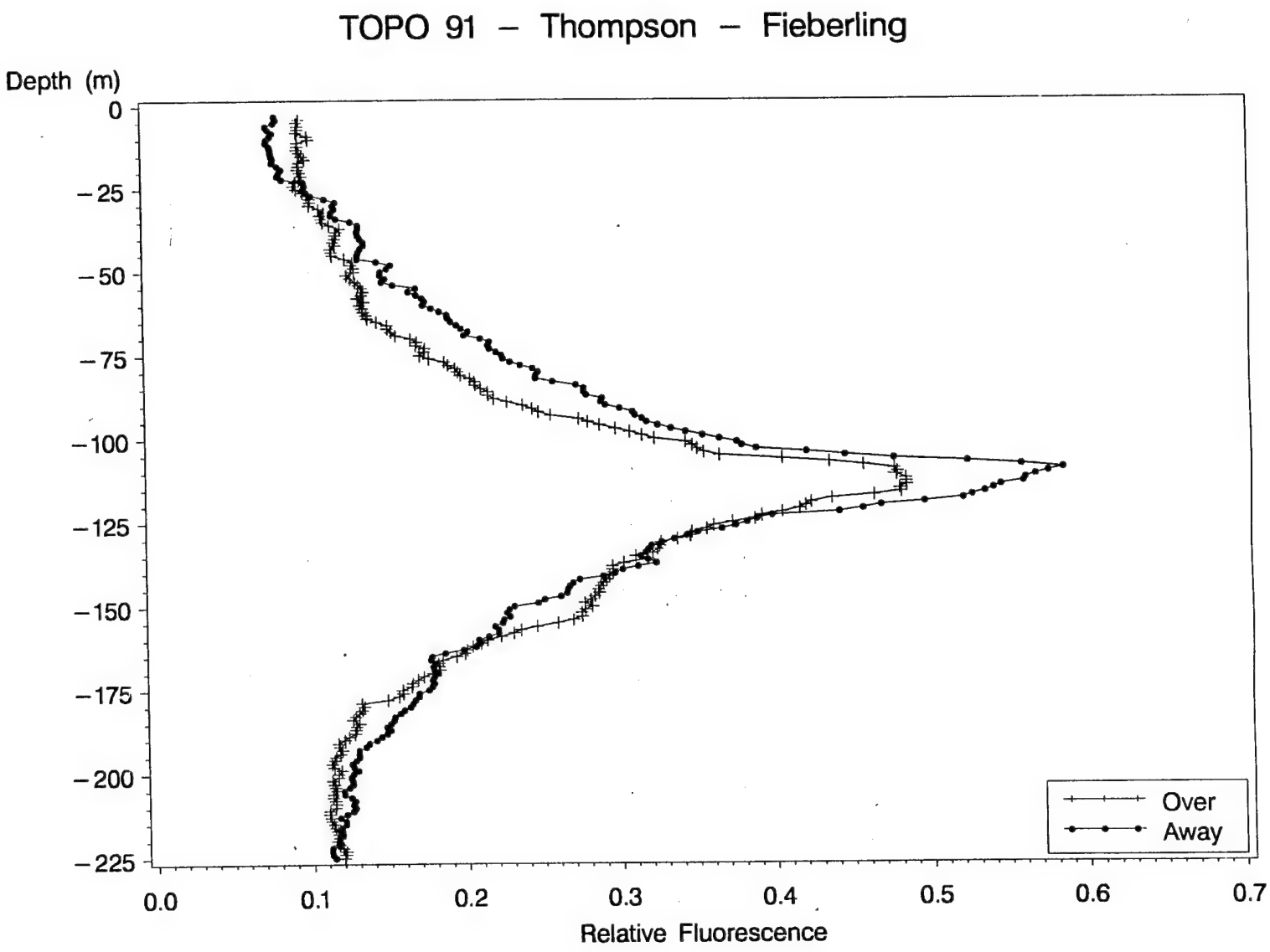
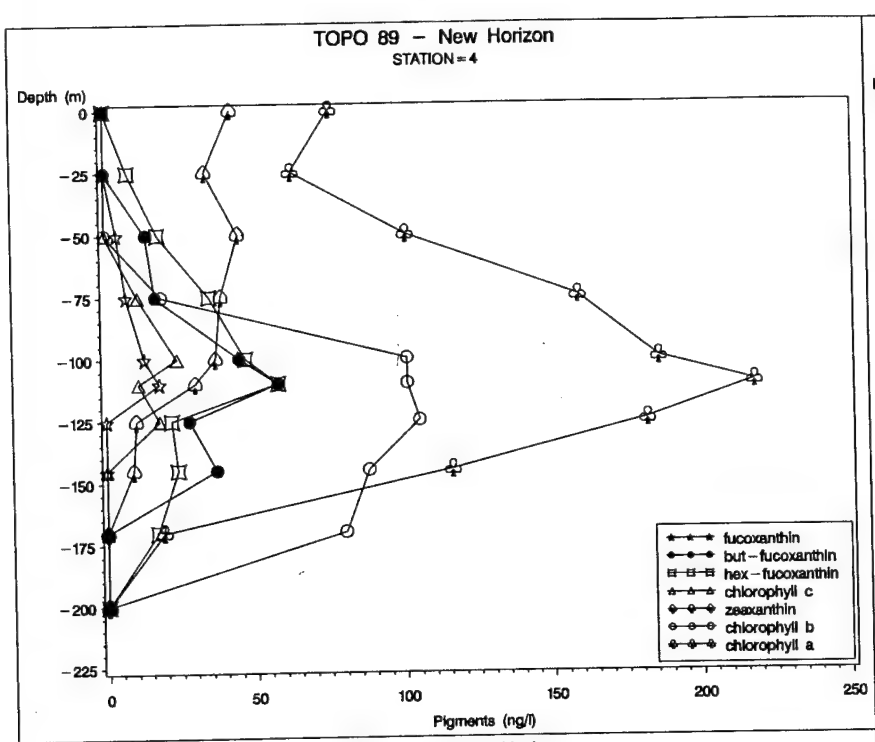
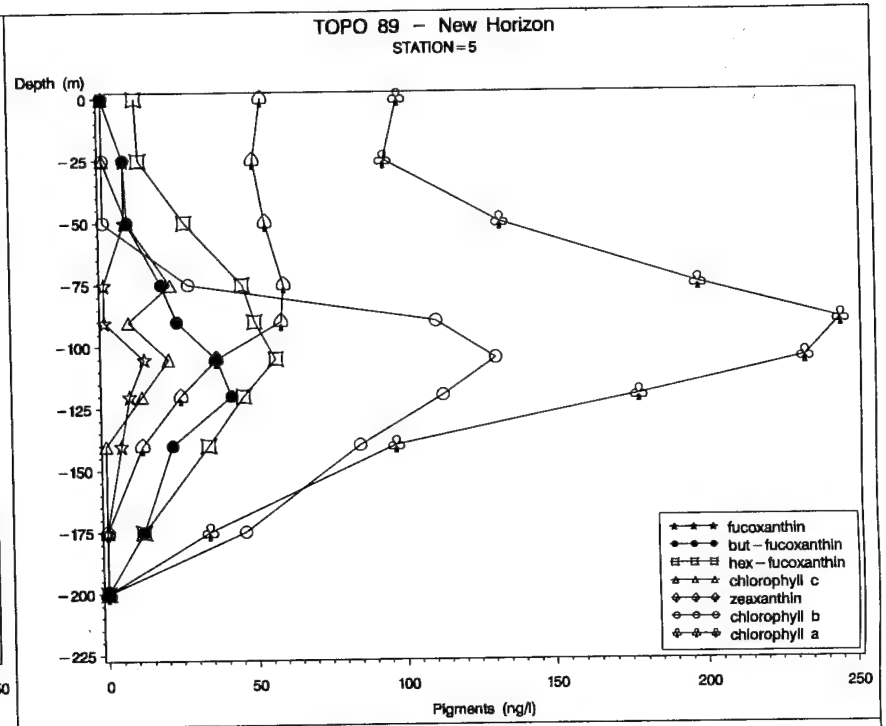


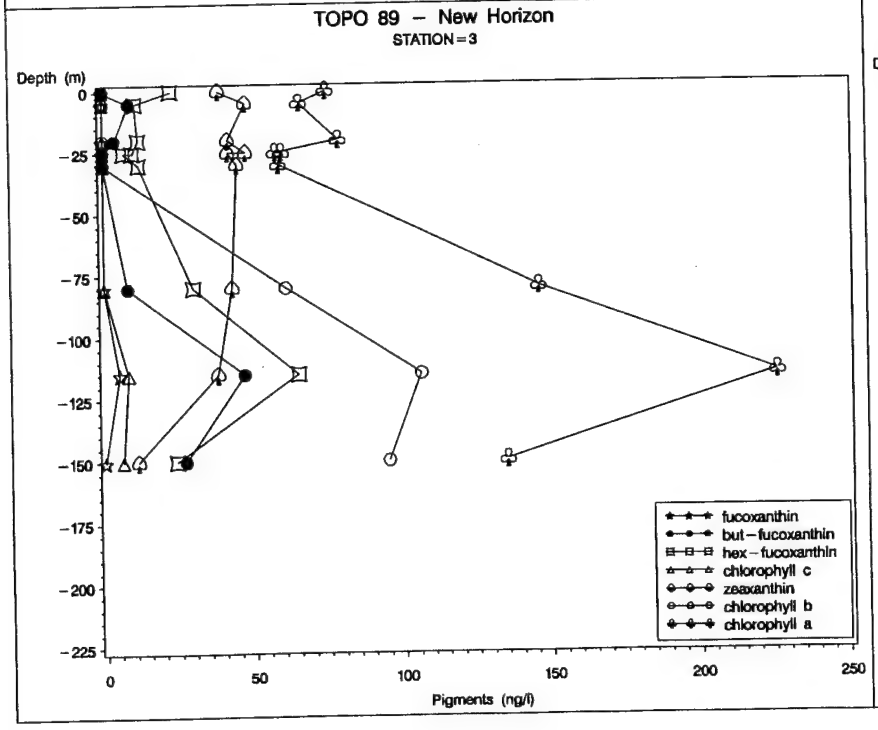

Figure 27. Comparison of vertical profiles of in situ fluorescence over and away from Fieberling Guyot from TOPO 91.

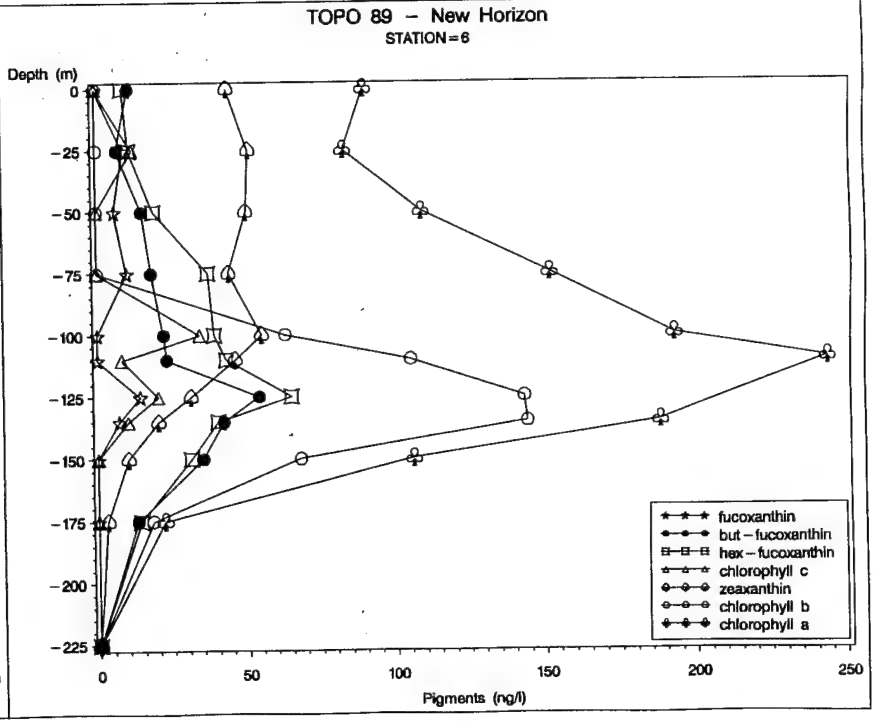
# Appendix A

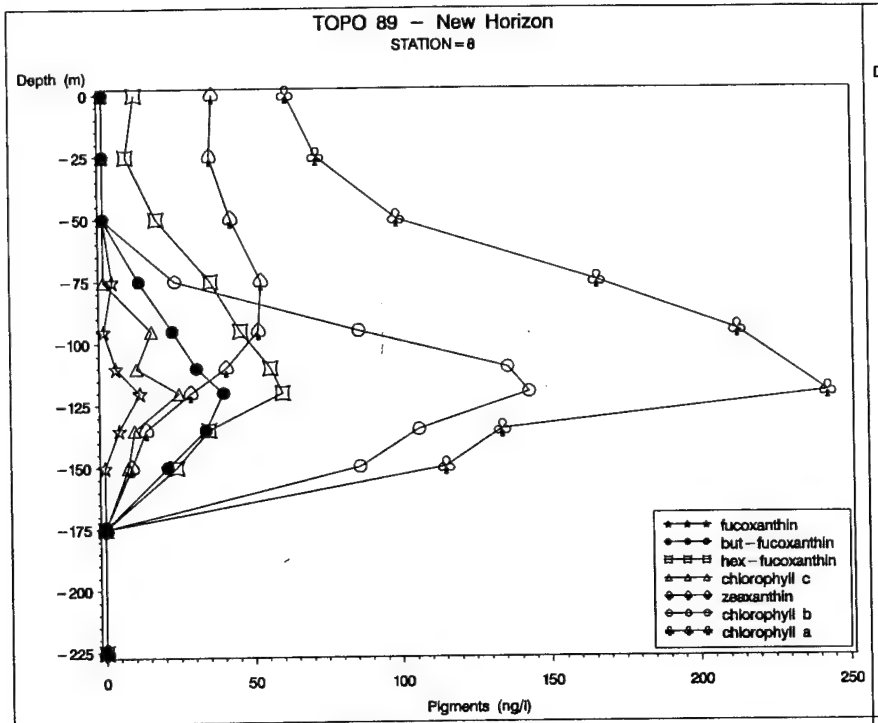
## Vertical Profiles of Phytoplankton Pigments from TOPO Water Column Biology Cruises

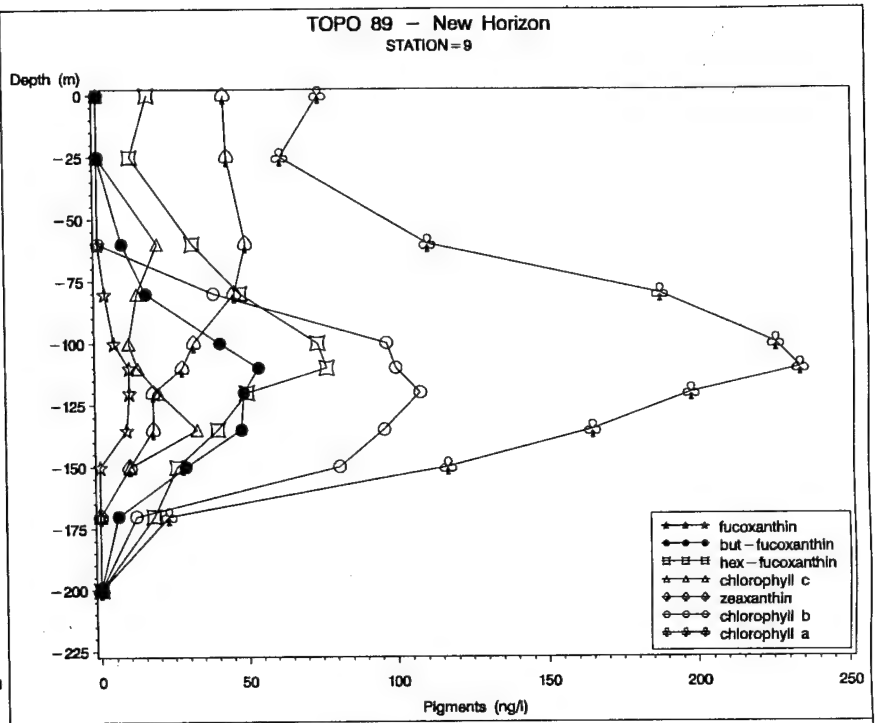

TOPO 89 – New Horizon
STATION=4
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

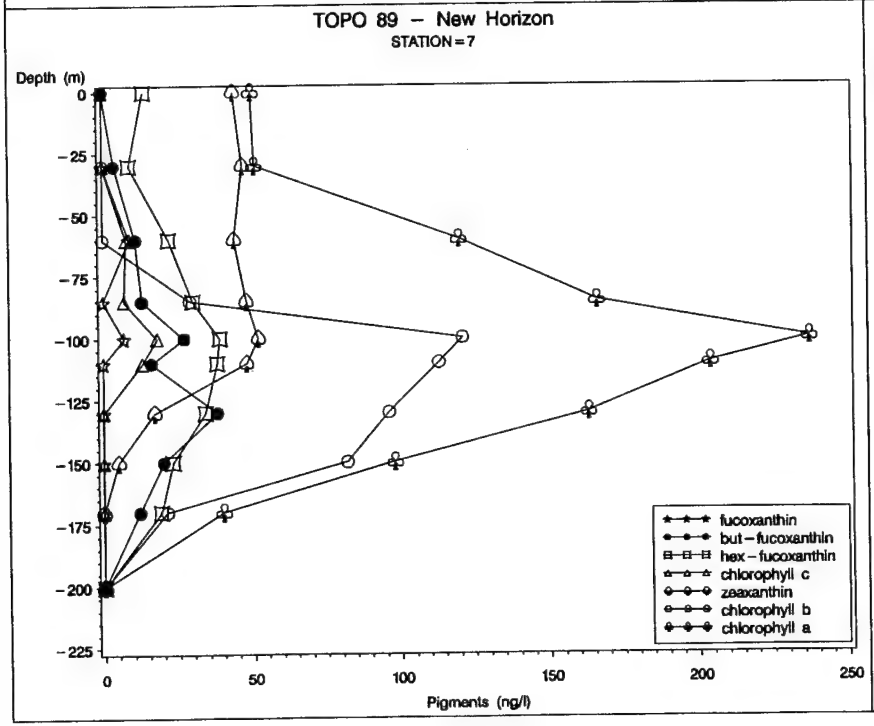

TOPO 89 – New Horizon
STATION=5
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

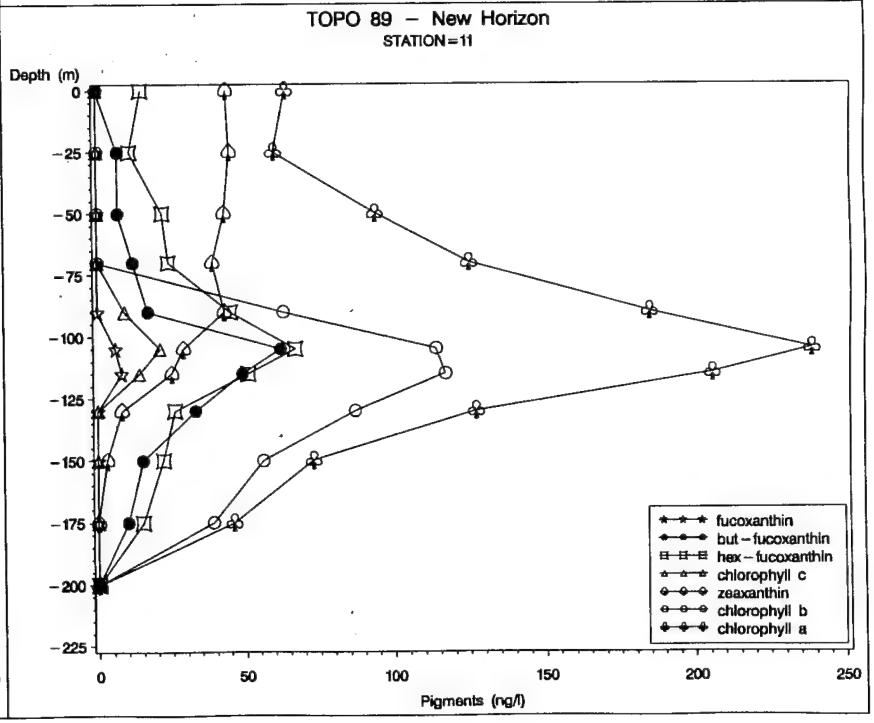

TOPO 89 – New Horizon
STATION=3
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

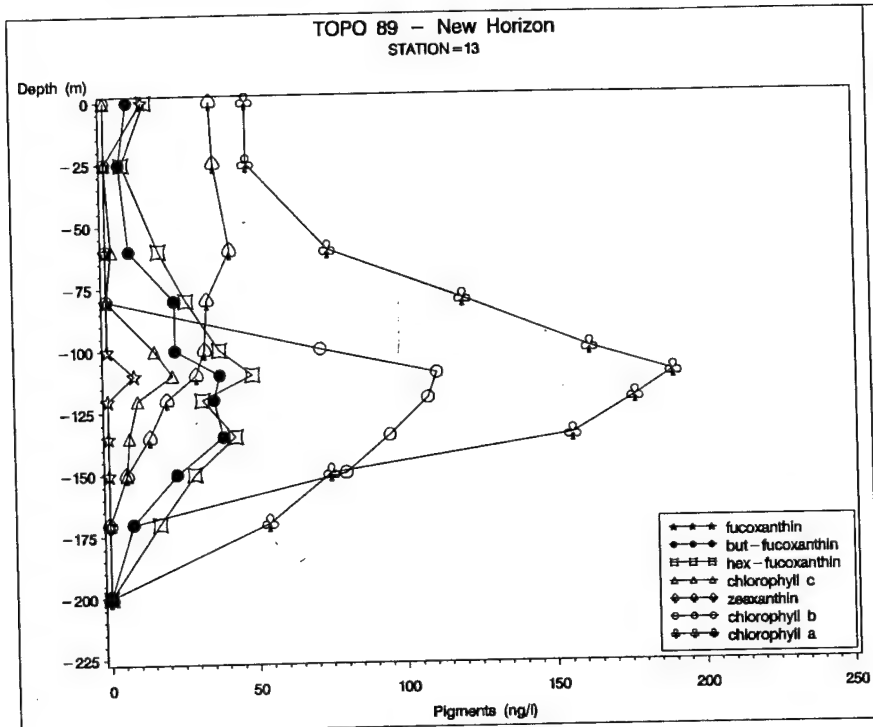

TOPO 89 – New Horizon
STATION=6
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

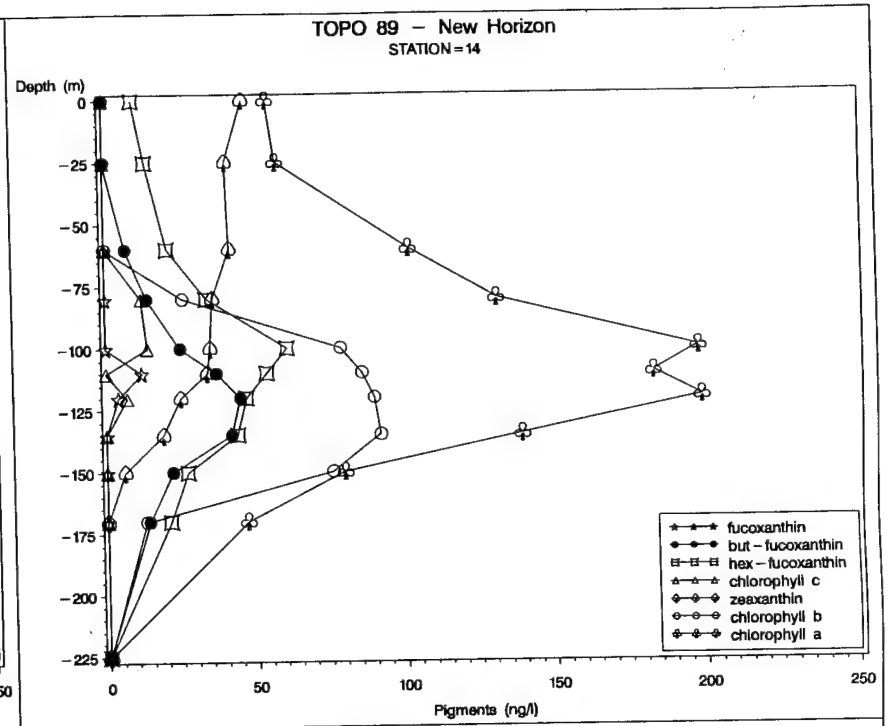

TOPO 89 – New Horizon
STATION=8
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

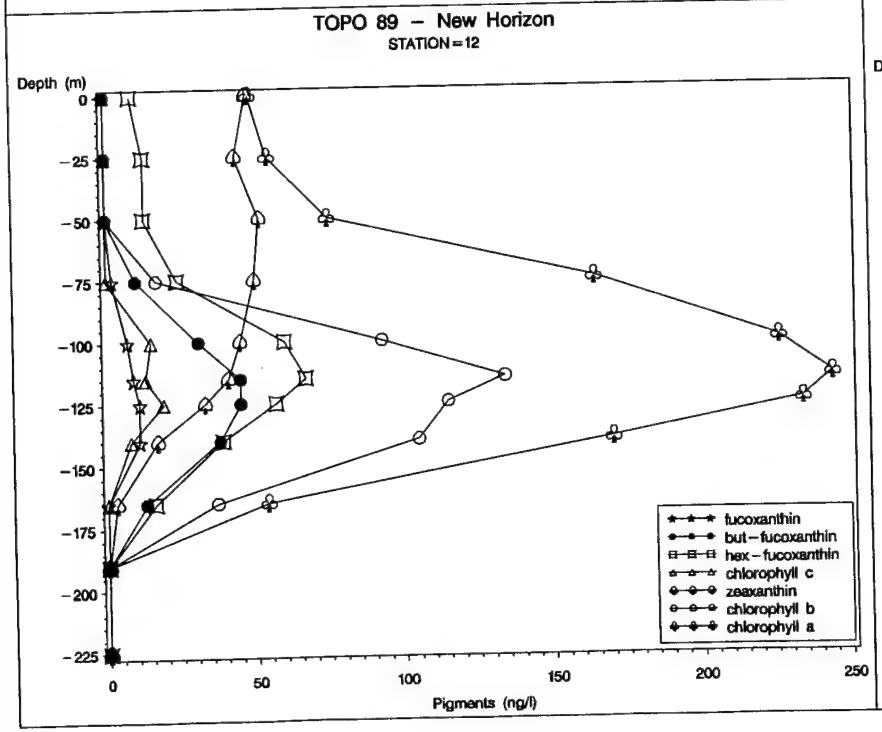

TOPO 89 – New Horizon
STATION=9
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

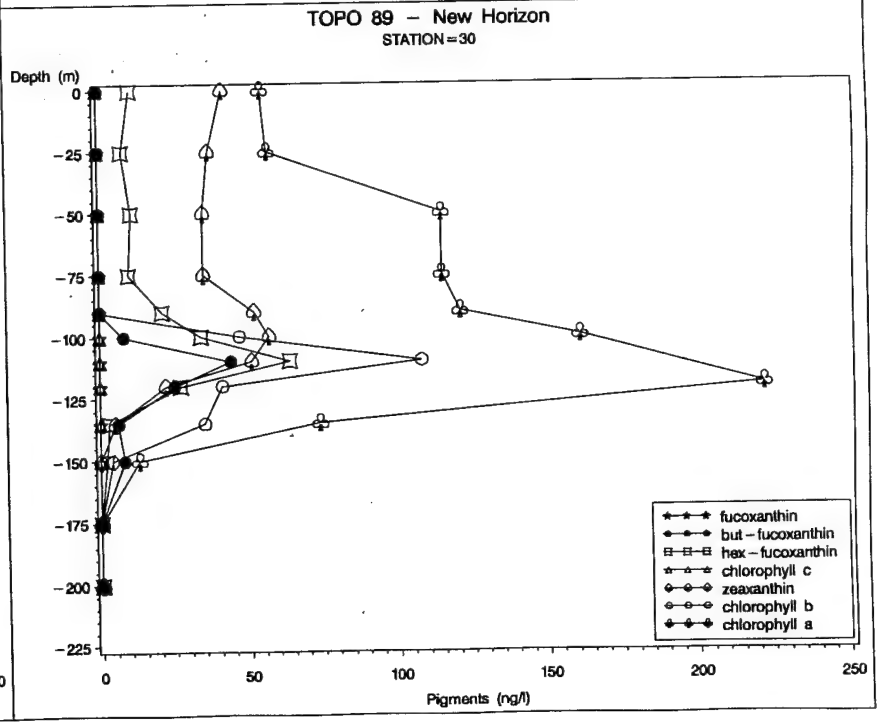

TOPO 89 – New Horizon
STATION=7
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

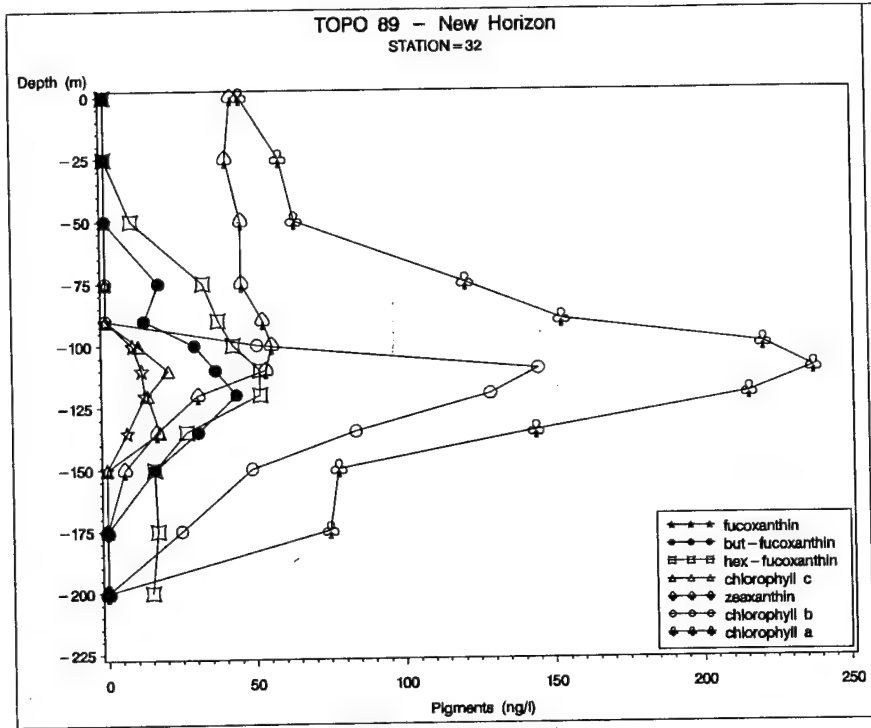

TOPO 89 – New Horizon
STATION=11
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

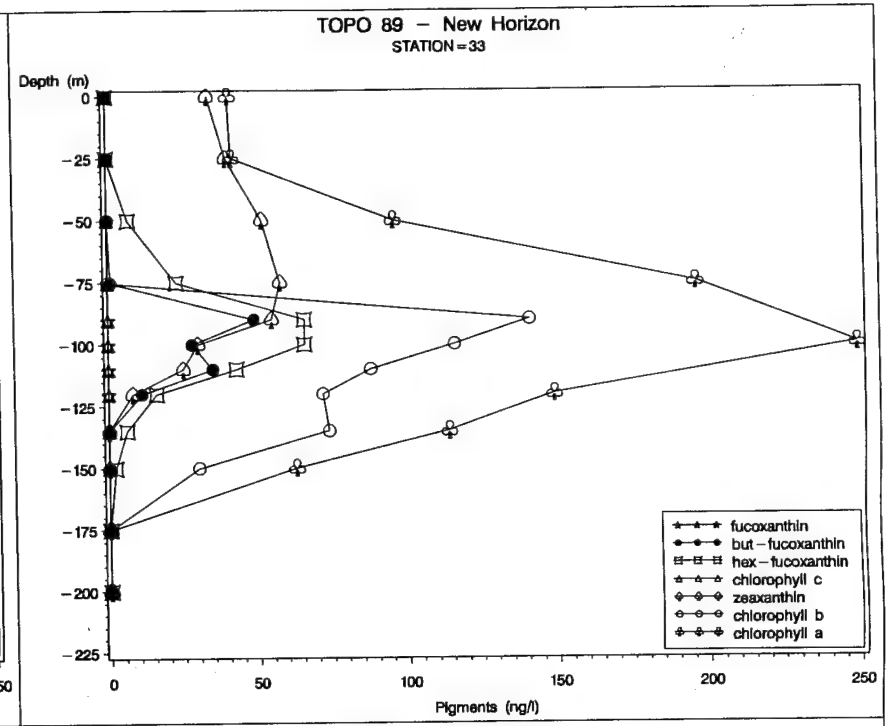

TOPO 89 – New Horizon
STATION=13
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

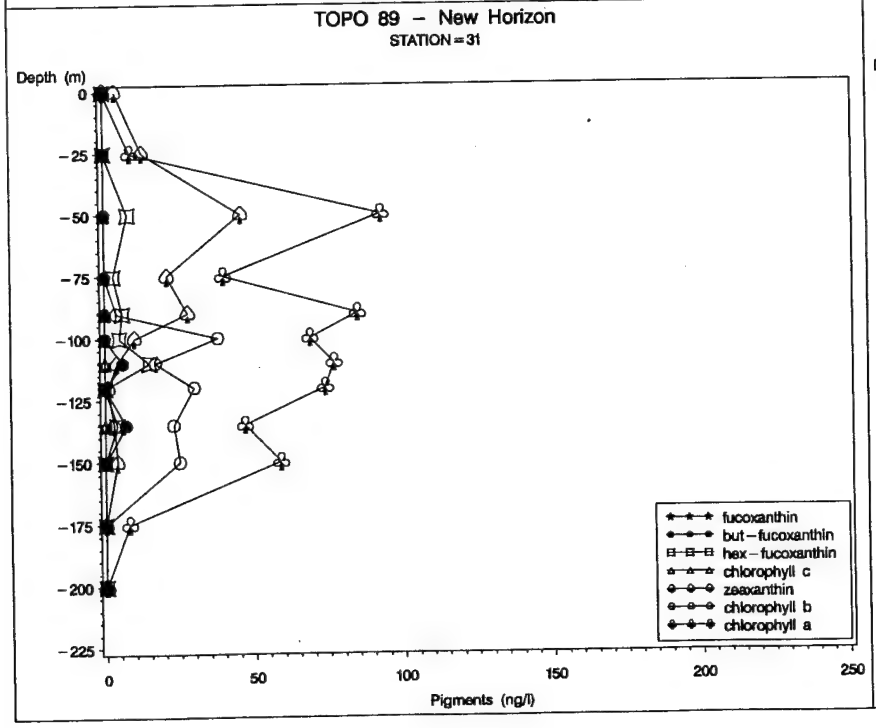

TOPO 89 – New Horizon
STATION=14
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

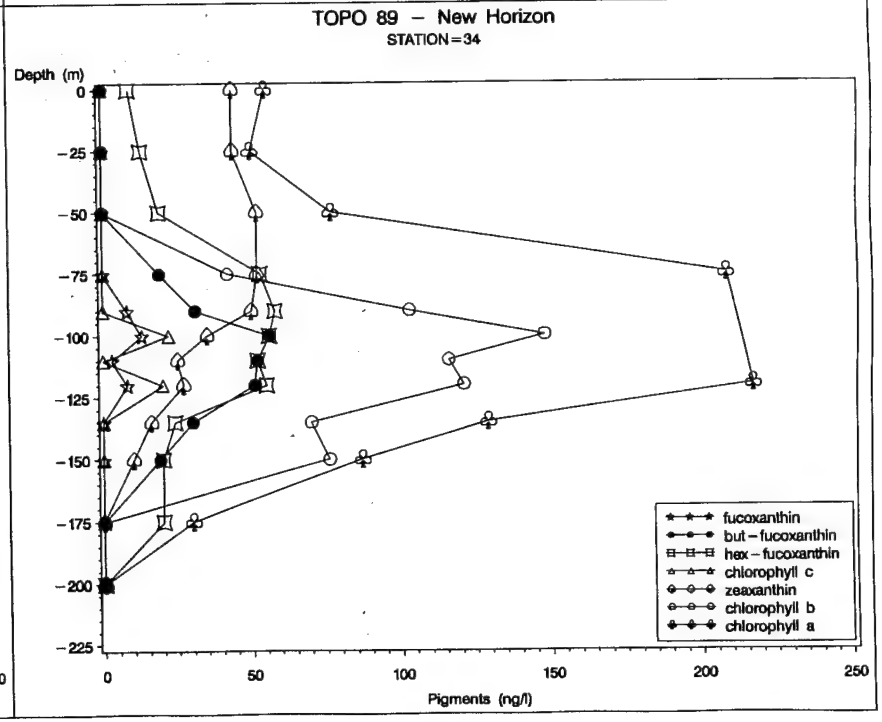

TOPO 89 – New Horizon
STATION=12
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a


TOPO 89 – New Horizon
STATION=30
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

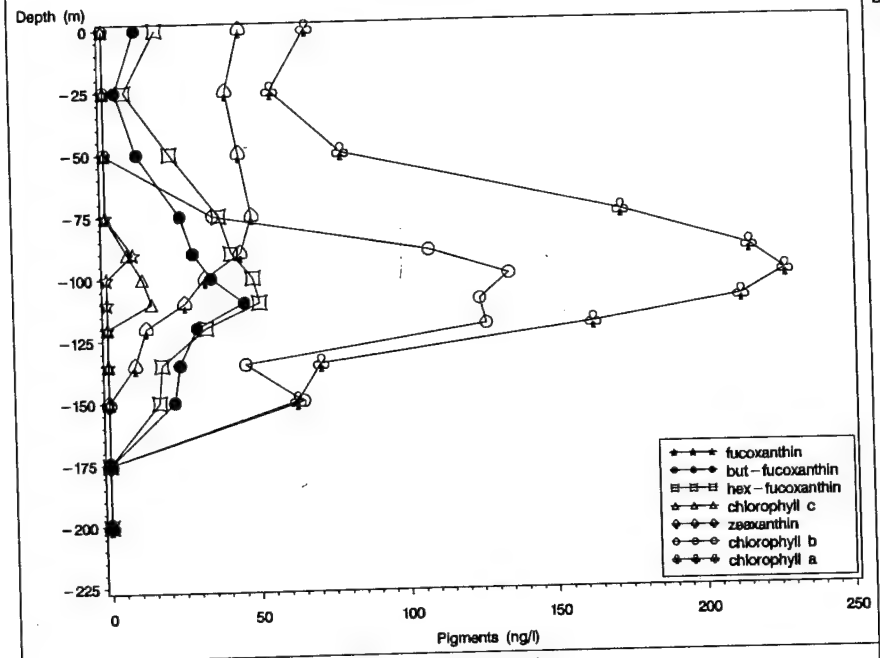

TOPO 89 – New Horizon
STATION=32
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a


TOPO 89 – New Horizon
STATION=33
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

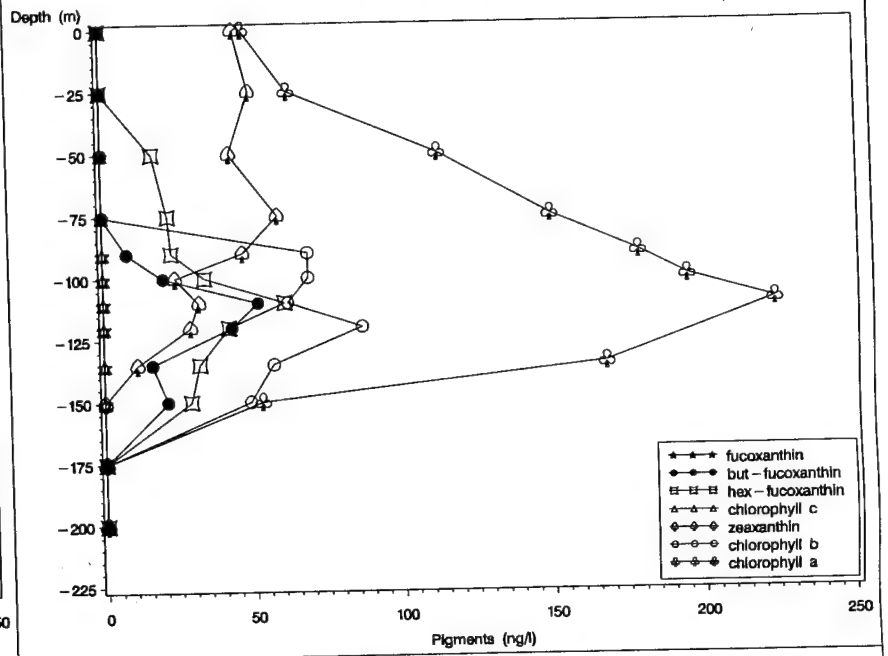

TOPO 89 – New Horizon
STATION=31
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a


TOPO 89 – New Horizon
STATION=34
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

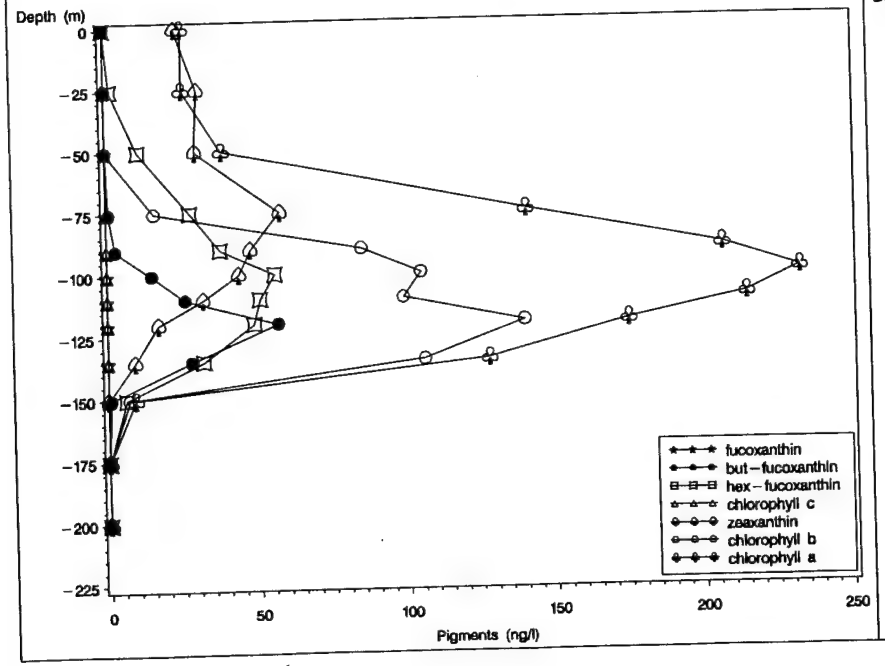
TOPO 89 – New Horizon
STATION=36



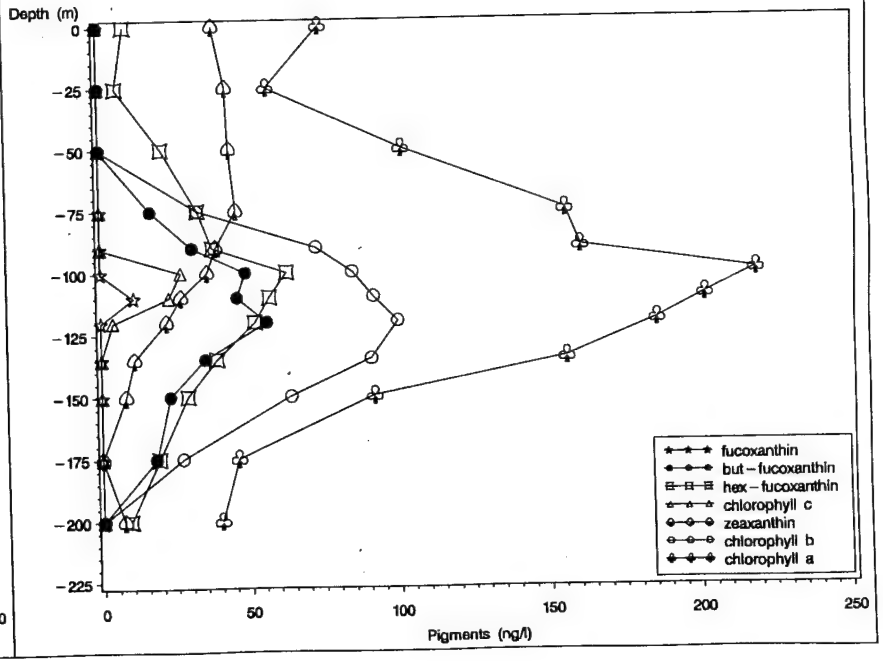

TOPO 89 – New Horizon
STATION=37

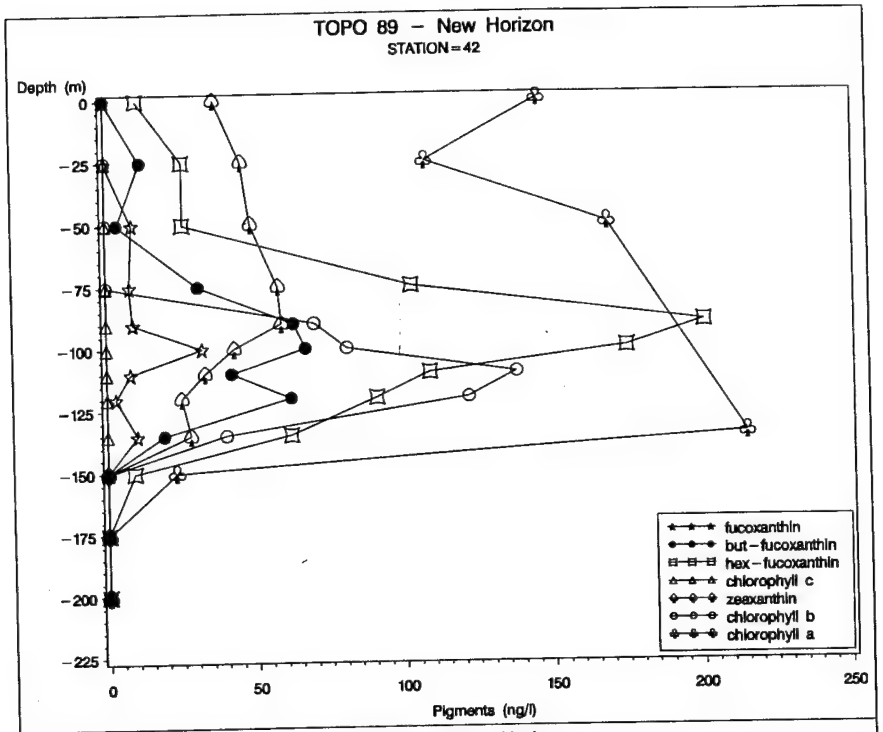


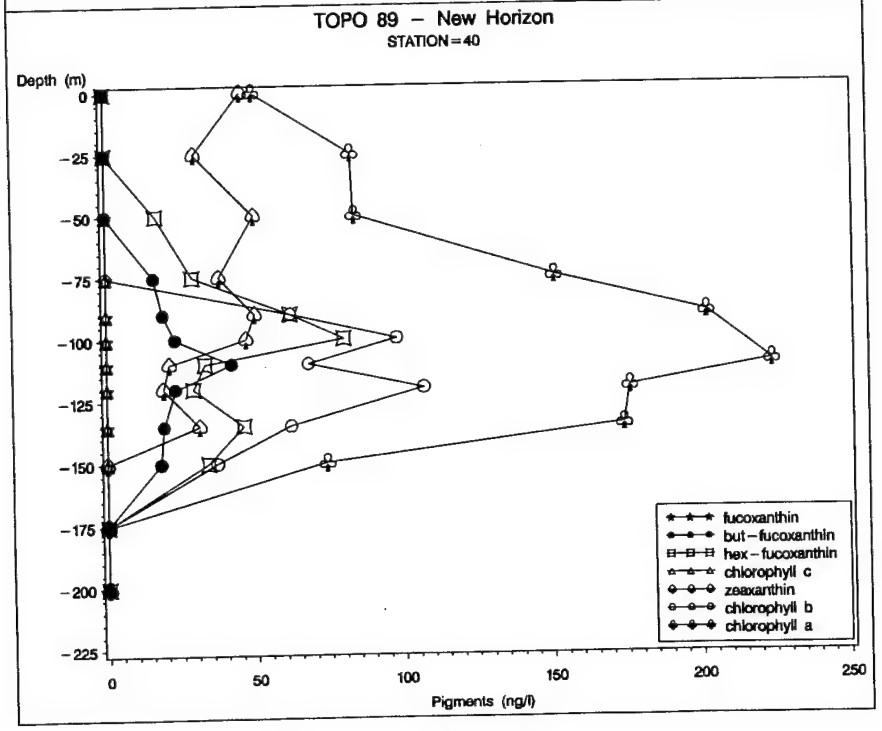

TOPO 89 – New Horizon
STATION=35

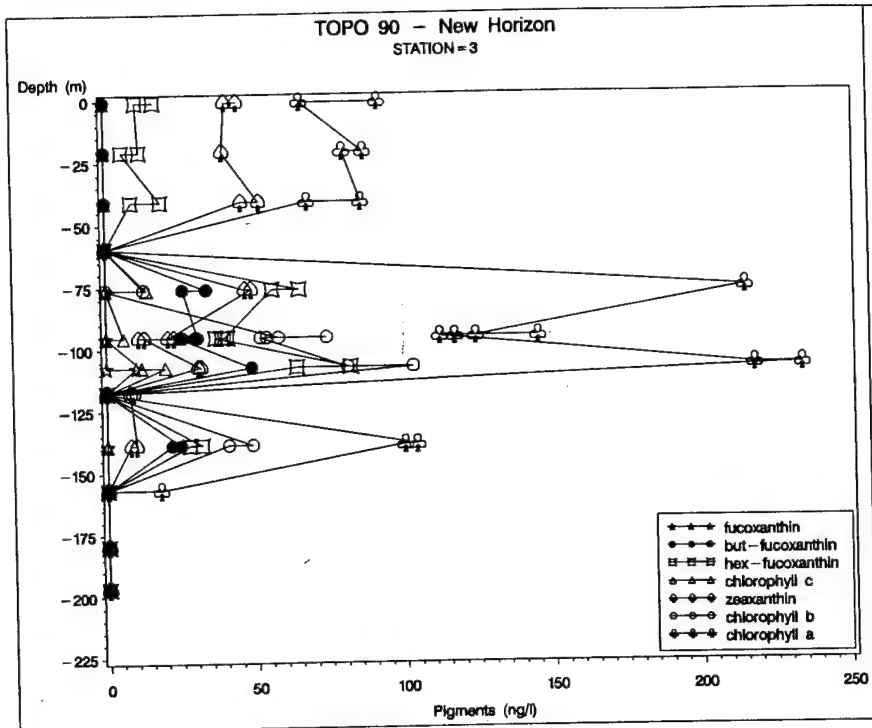


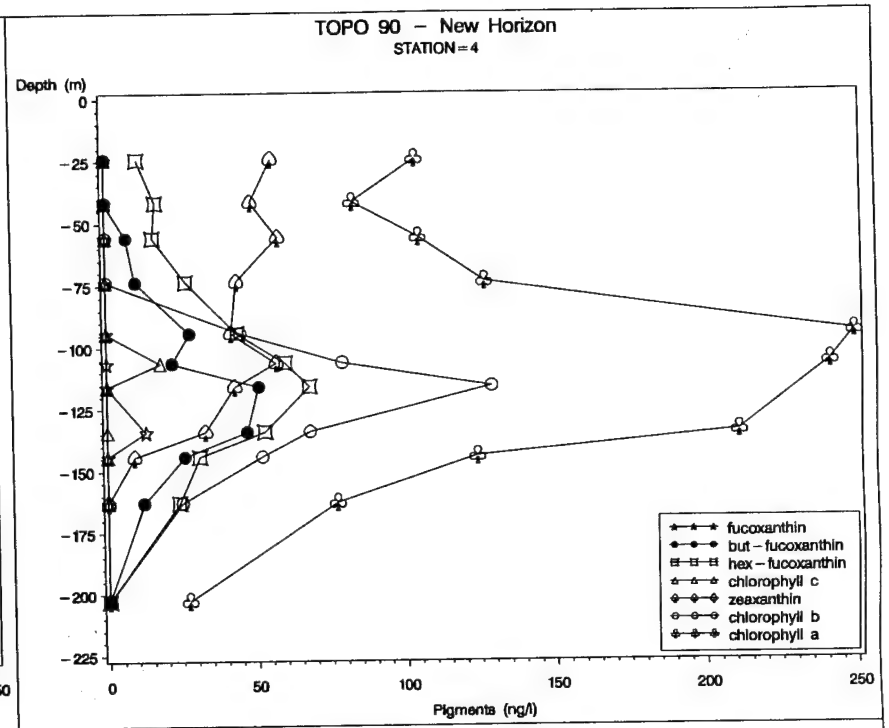

TOPO 89 – New Horizon
STATION=38

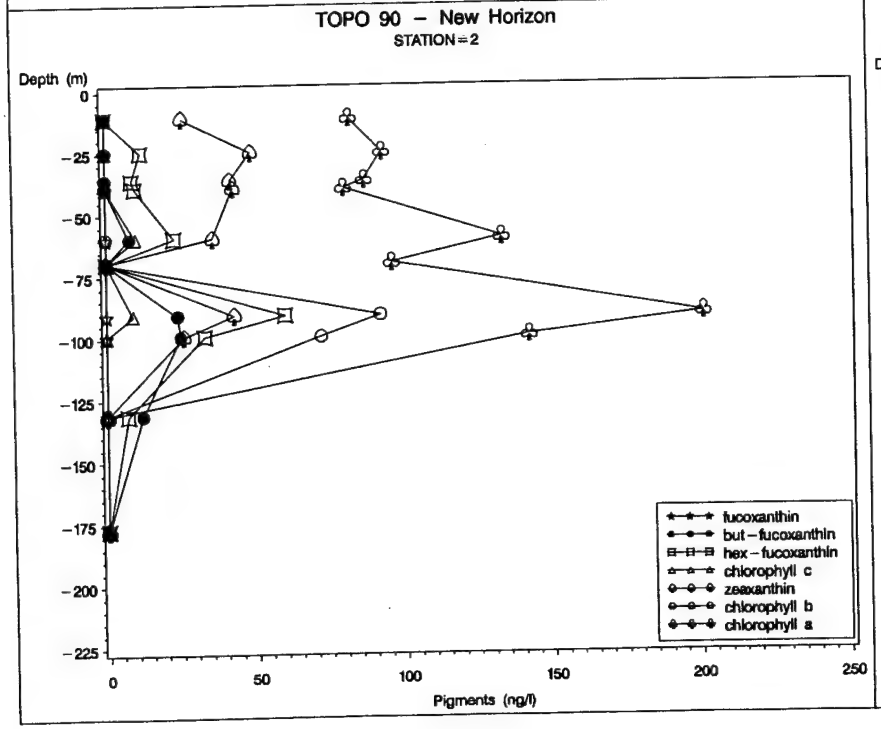


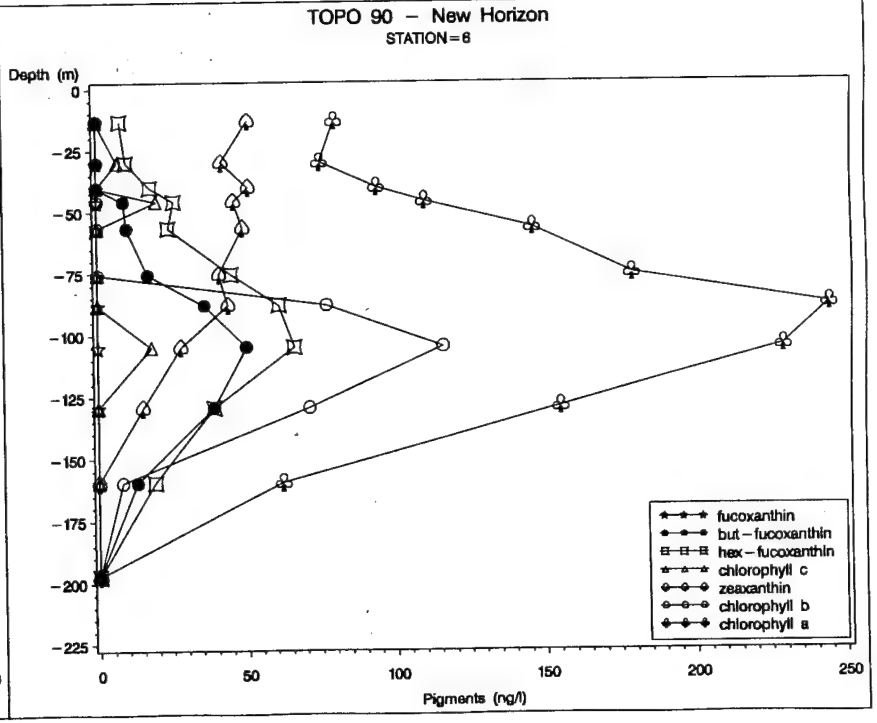

TOPO 89 – New Horizon
STATION=42
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a


TOPO 89 – New Horizon
STATION=40
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

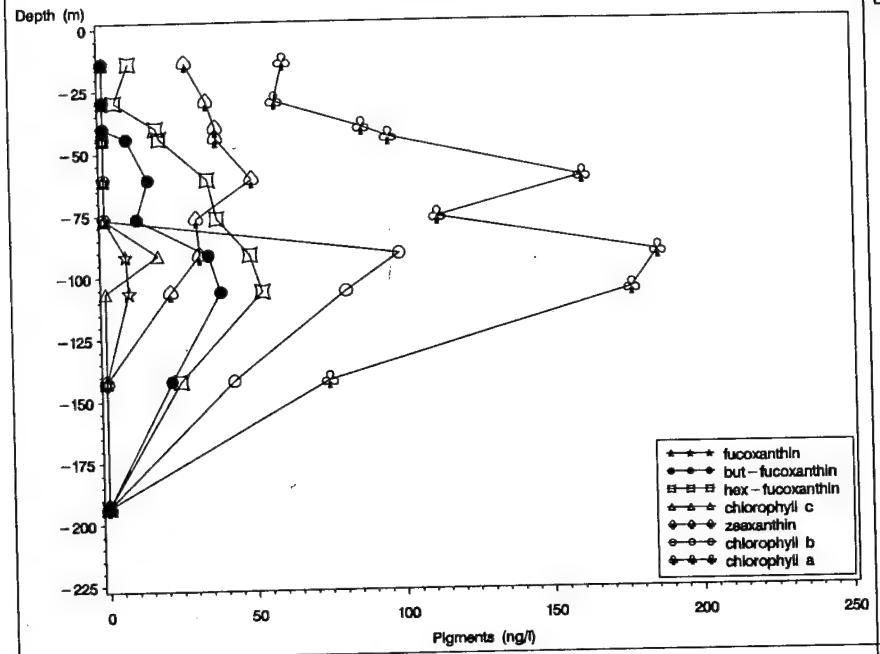

TOPO 90 – New Horizon
STATION=3
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a


TOPO 90 – New Horizon
STATION=4
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

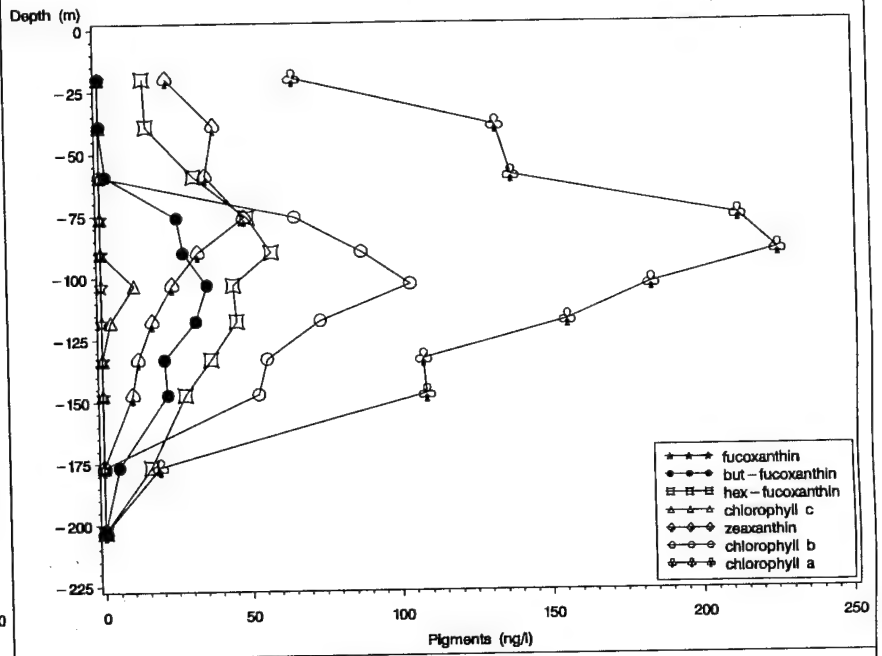

TOPO 90 – New Horizon
STATION=2
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a


TOPO 90 – New Horizon
STATION=6
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

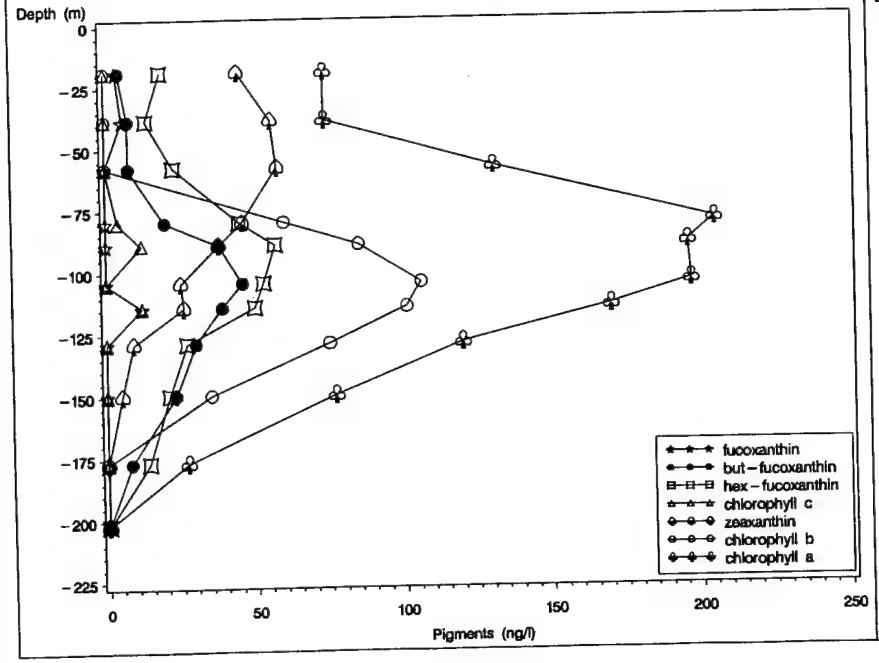
TOPO 90 – New Horizon
STATION = 8



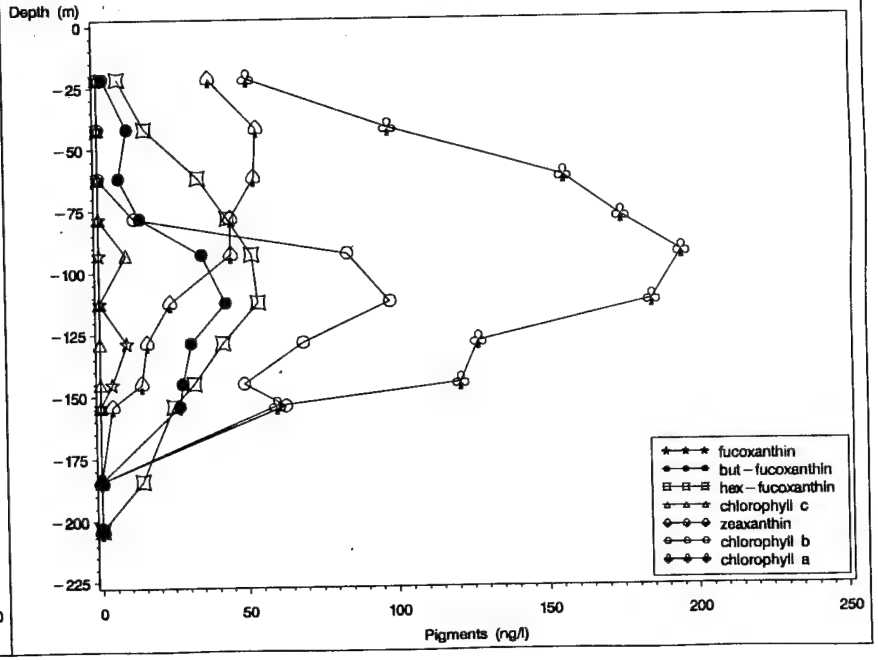

TOPO 90 – New Horizon
STATION = 9

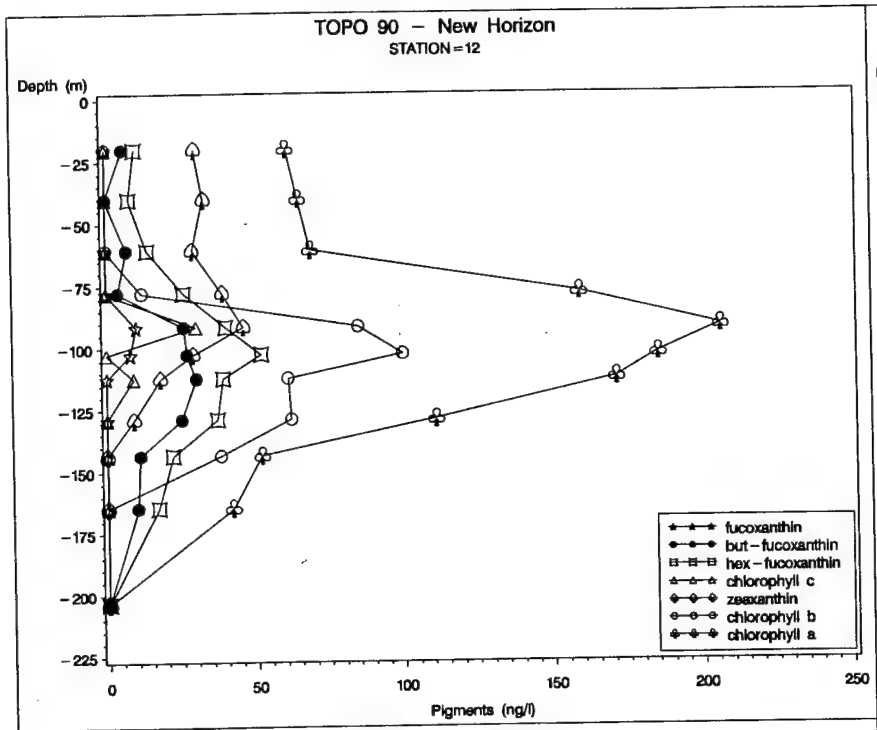


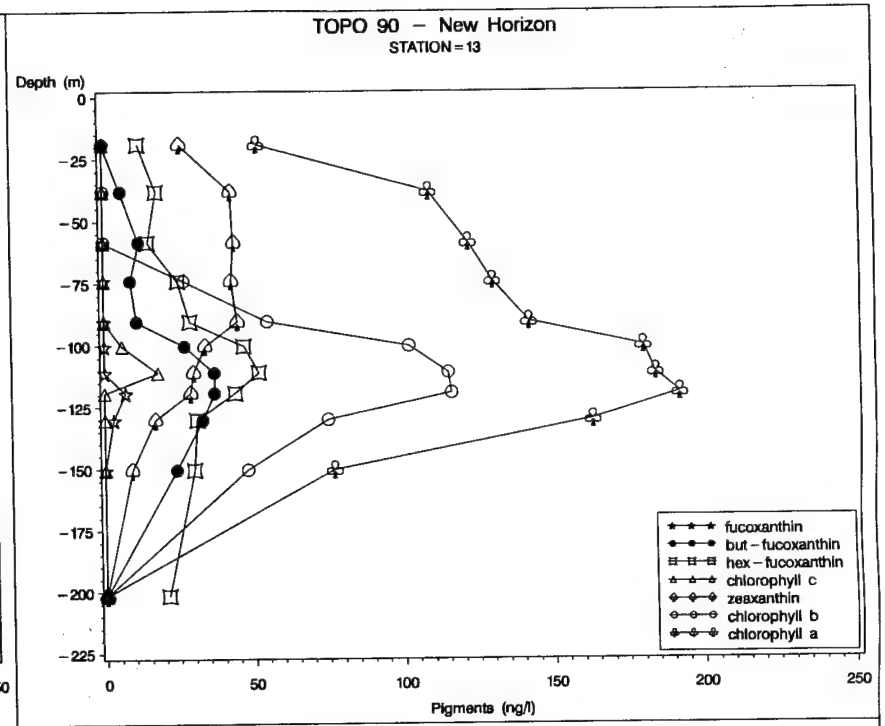

TOPO 90 – New Horizon
STATION = 7

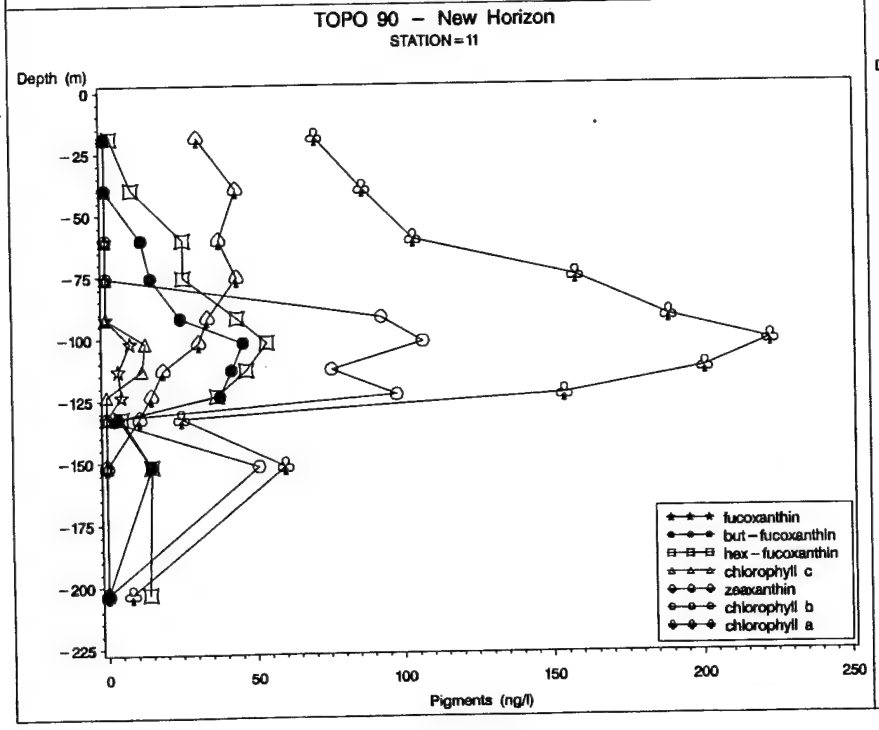


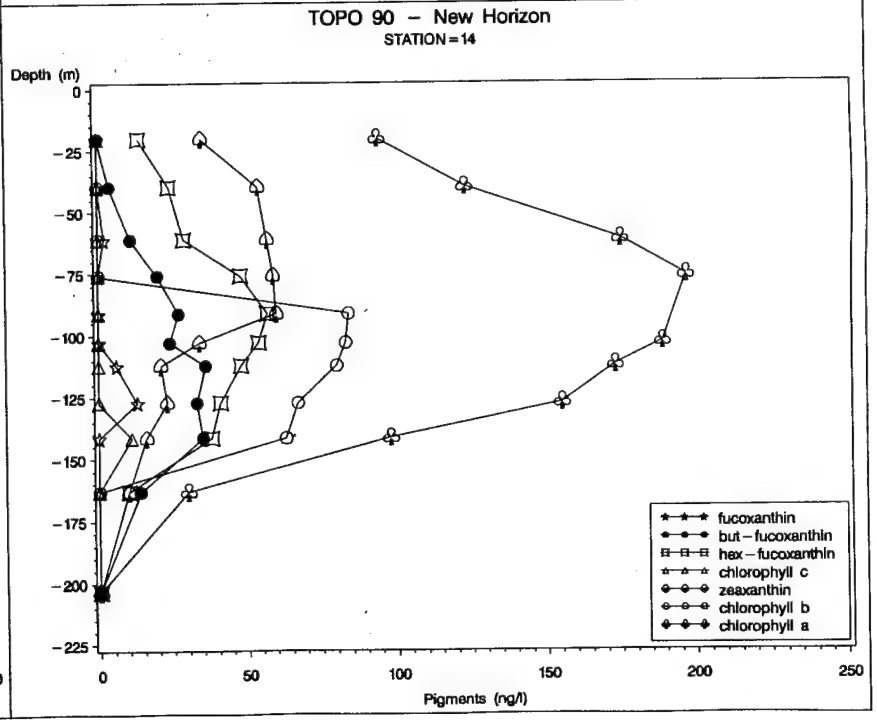

TOPO 90 – New Horizon
STATION = 10

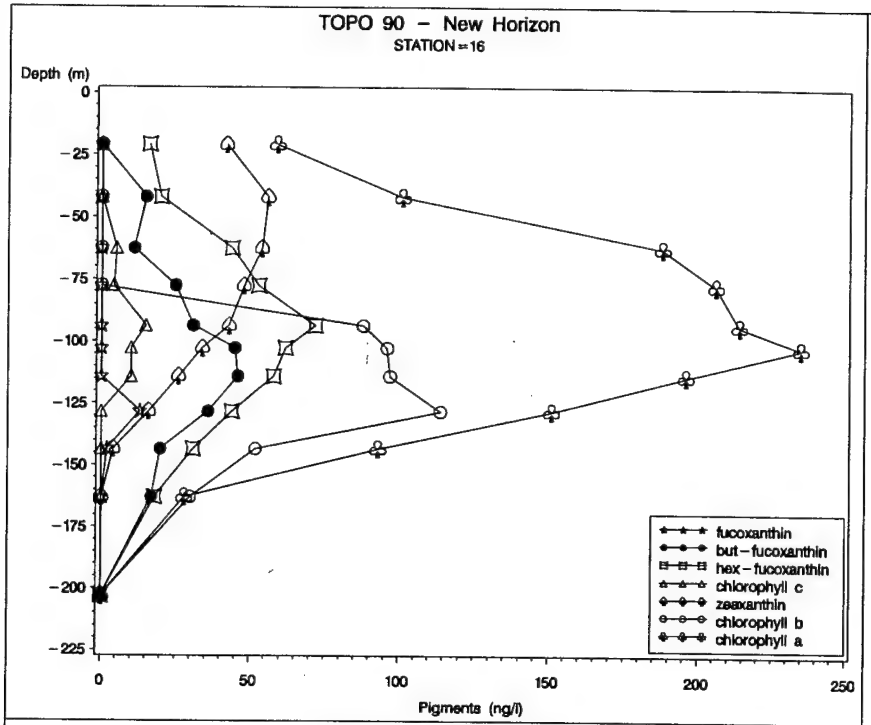


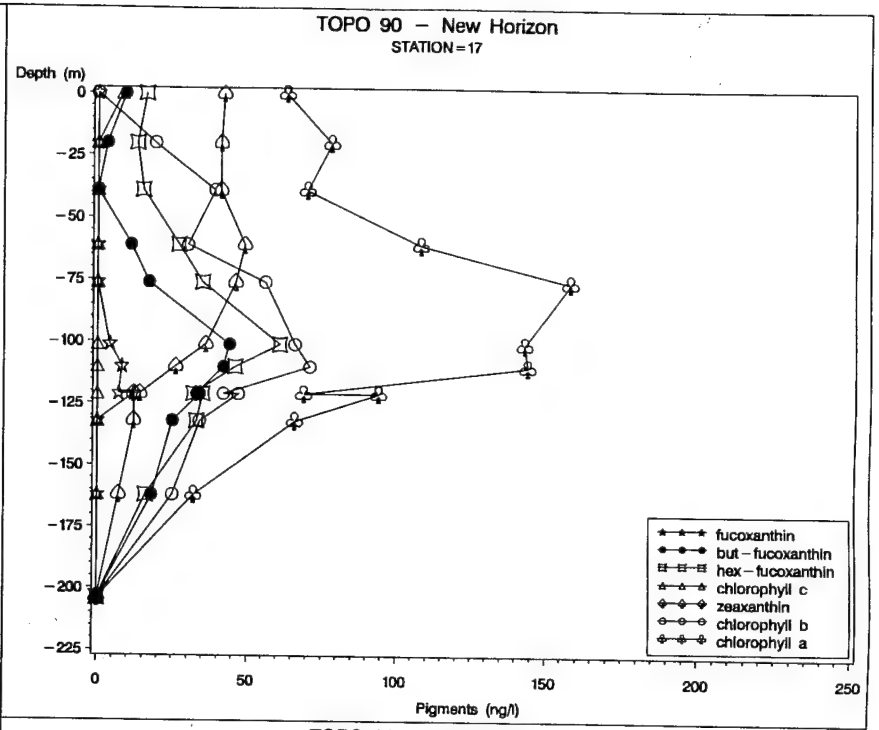

TOPO 90 – New Horizon
STATION = 12
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but – fucoxanthin
hex – fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

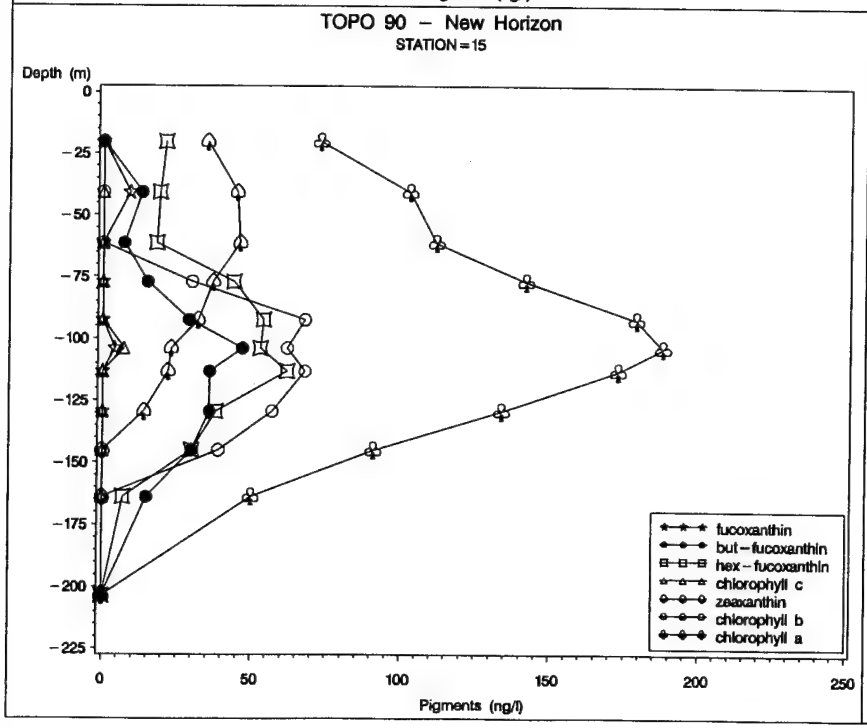

TOPO 90 – New Horizon
STATION = 13
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but – fucoxanthin
hex – fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

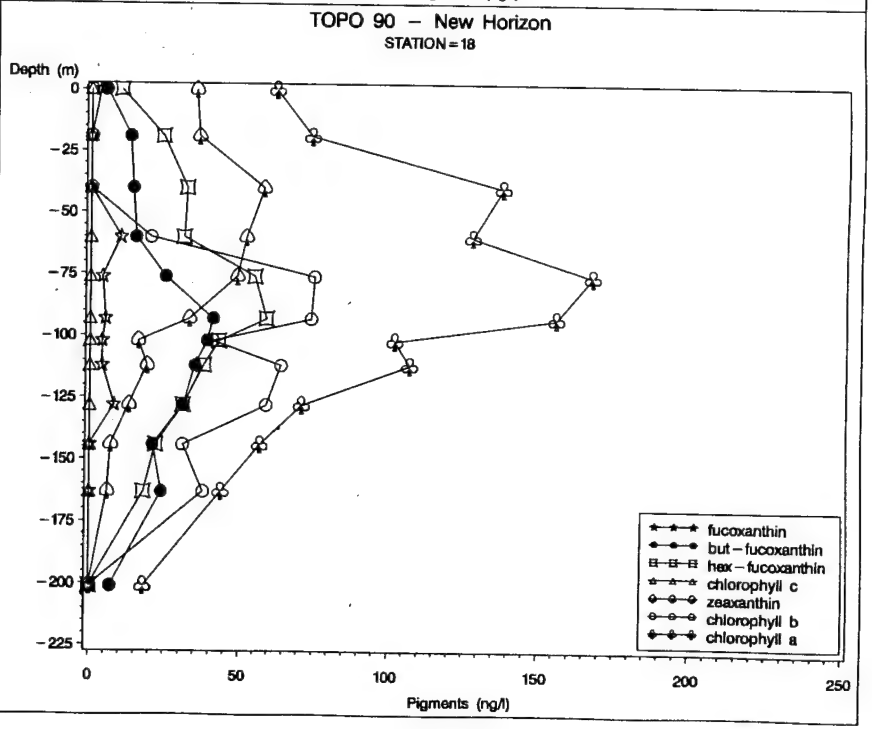

TOPO 90 – New Horizon
STATION = 11
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but – fucoxanthin
hex – fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

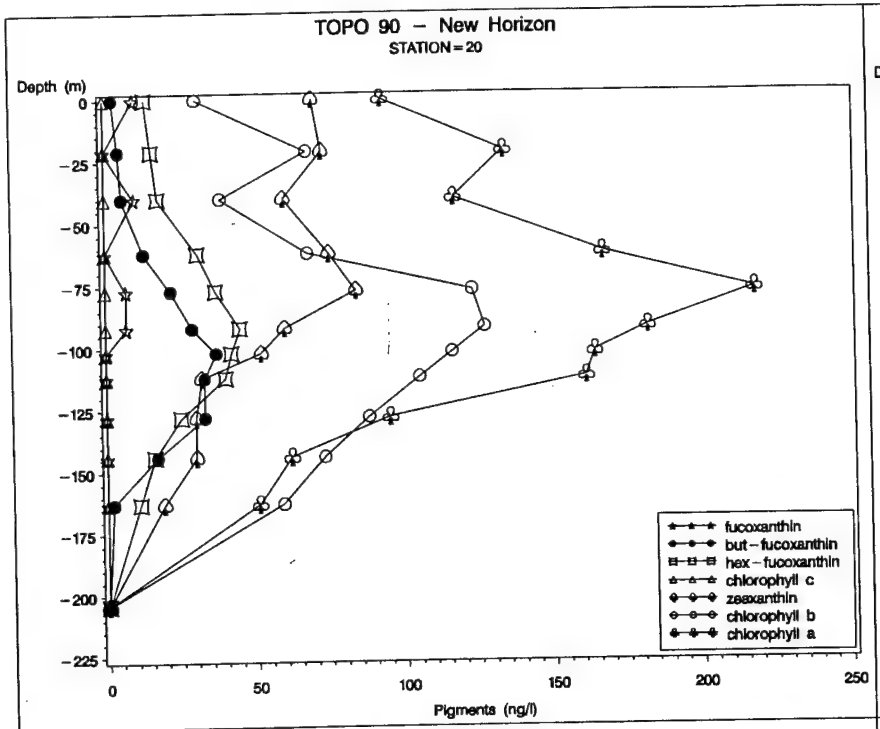

TOPO 90 – New Horizon
STATION = 14
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but – fucoxanthin
hex – fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

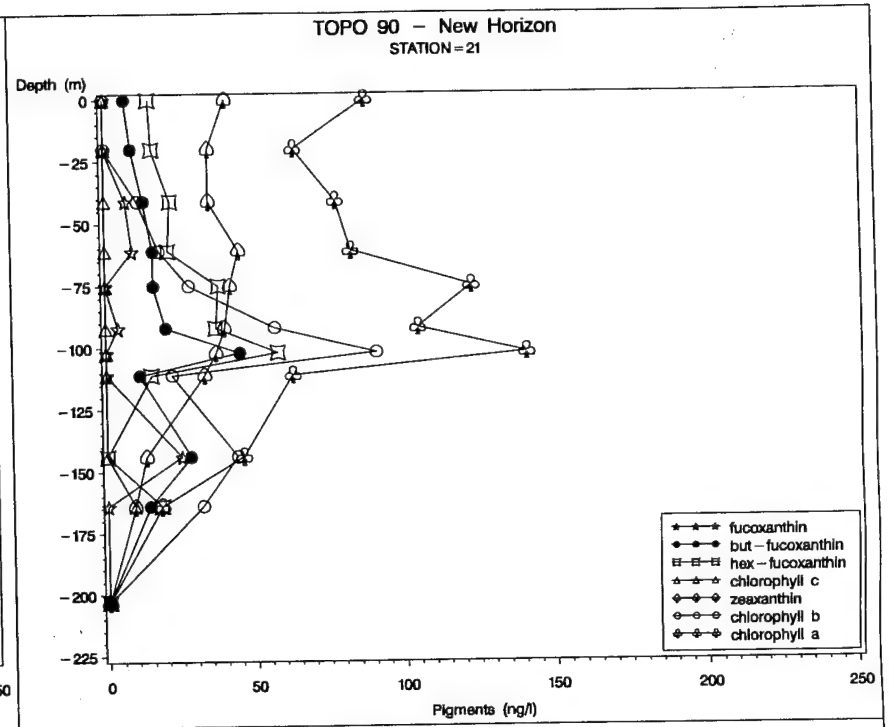

TOPO 90 – New Horizon
STATION = 16
Depth (m)
0
−25
−50
−75
−100
−125
−150
−175
−200
−225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but – fucoxanthin
hex – fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

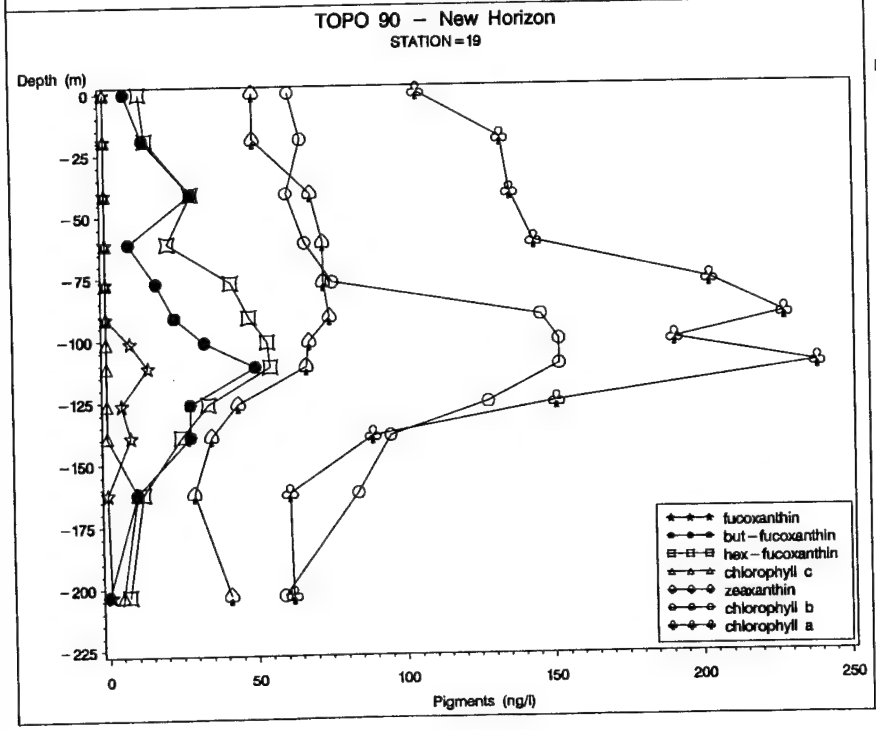

TOPO 90 – New Horizon
STATION = 17
Depth (m)
0
−25
−50
−75
−100
−125
−150
−175
−200
−225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but – fucoxanthin
hex – fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

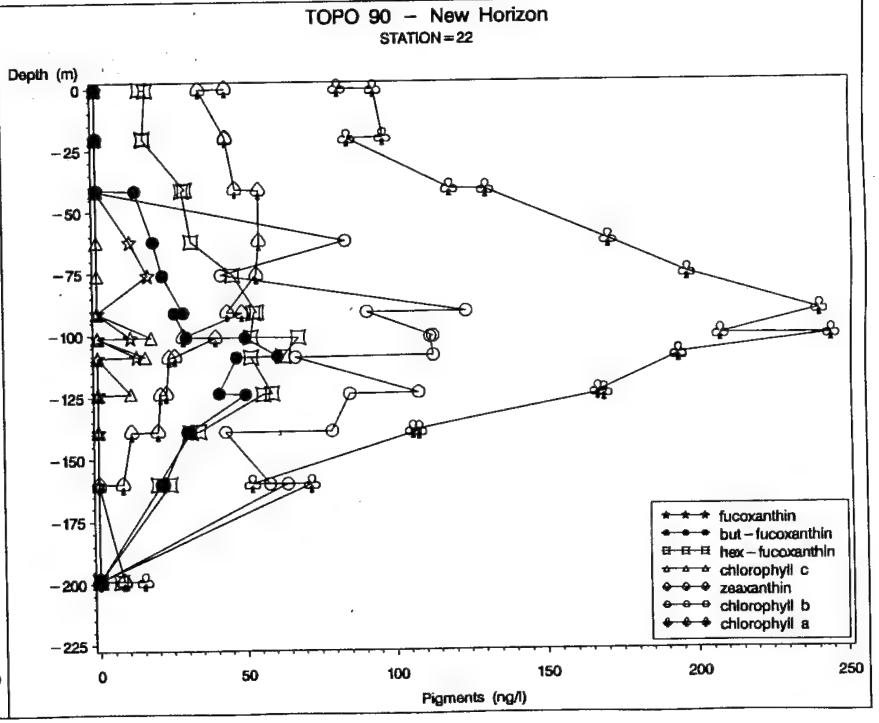

TOPO 90 – New Horizon
STATION = 15
Depth (m)
0
−25
−50
−75
−100
−125
−150
−175
−200
−225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but – fucoxanthin
hex – fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

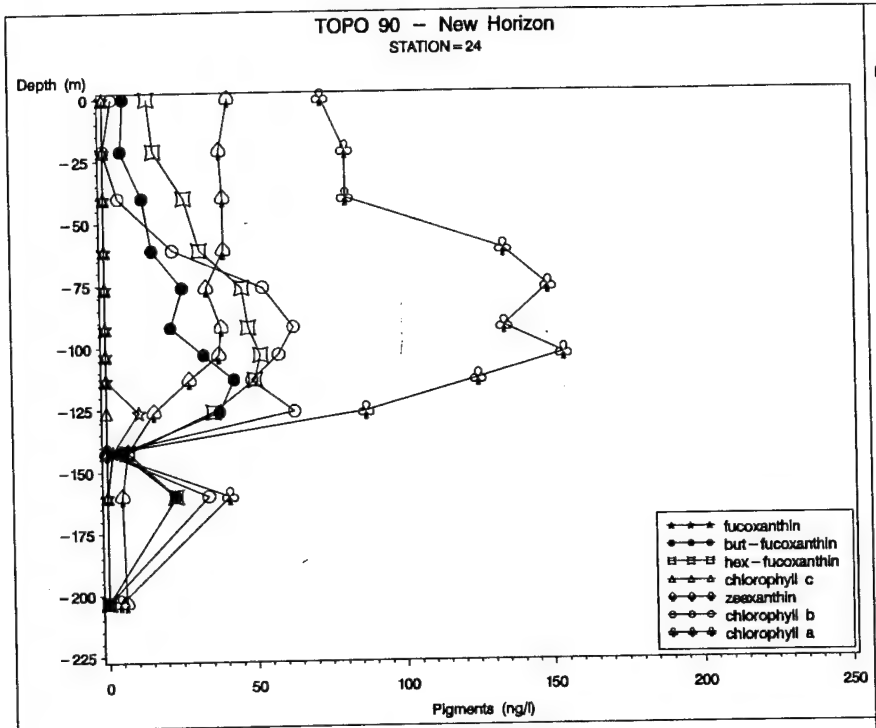

TOPO 90 – New Horizon
STATION = 18
Depth (m)
0
−25
−50
−75
−100
−125
−150
−175
−200
−225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but – fucoxanthin
hex – fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

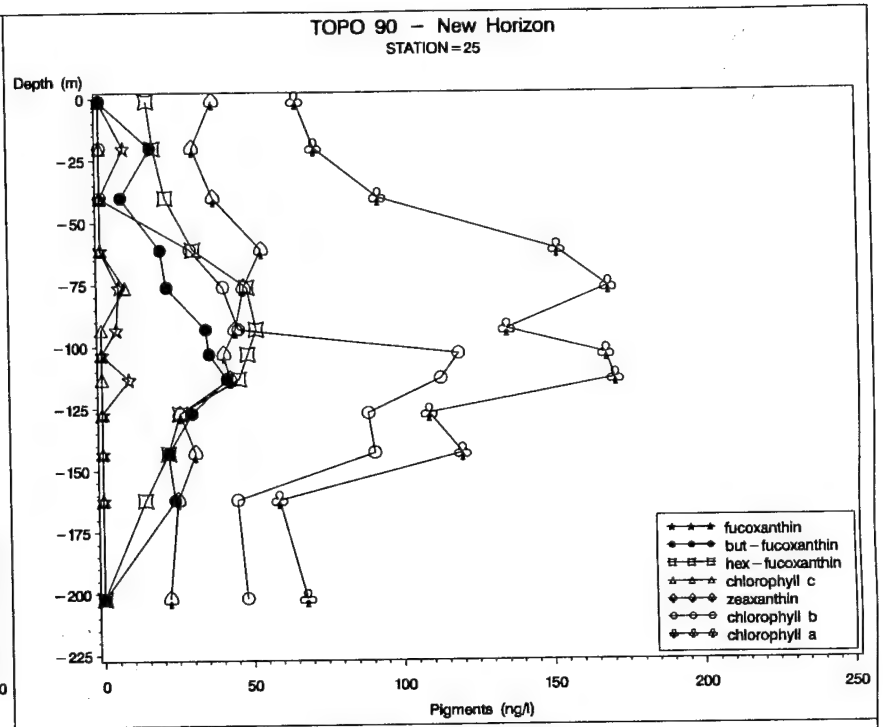

TOPO 90 – New Horizon
STATION=20
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

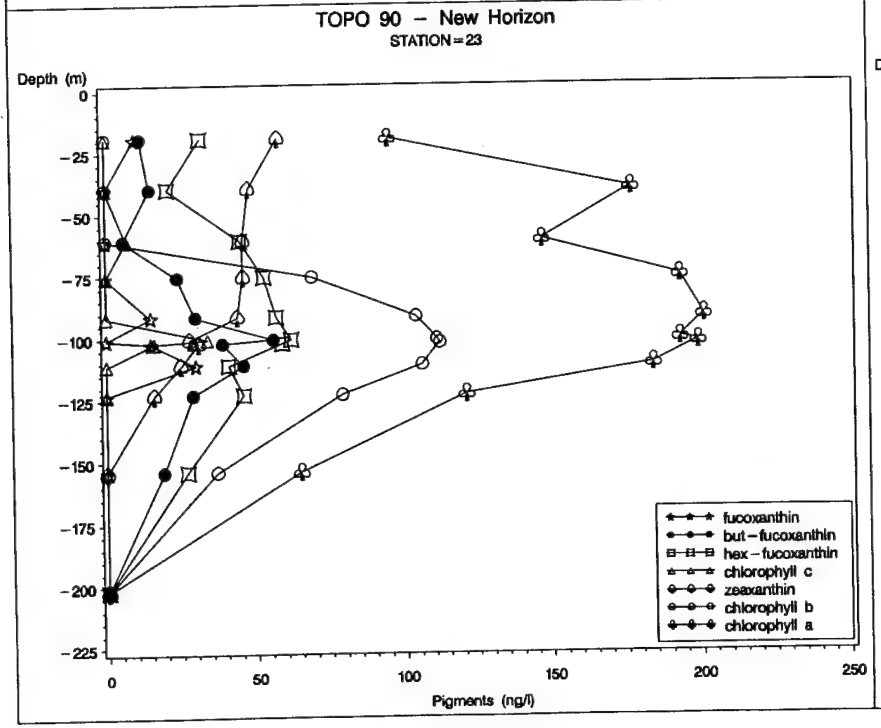

TOPO 90 – New Horizon
STATION=21
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

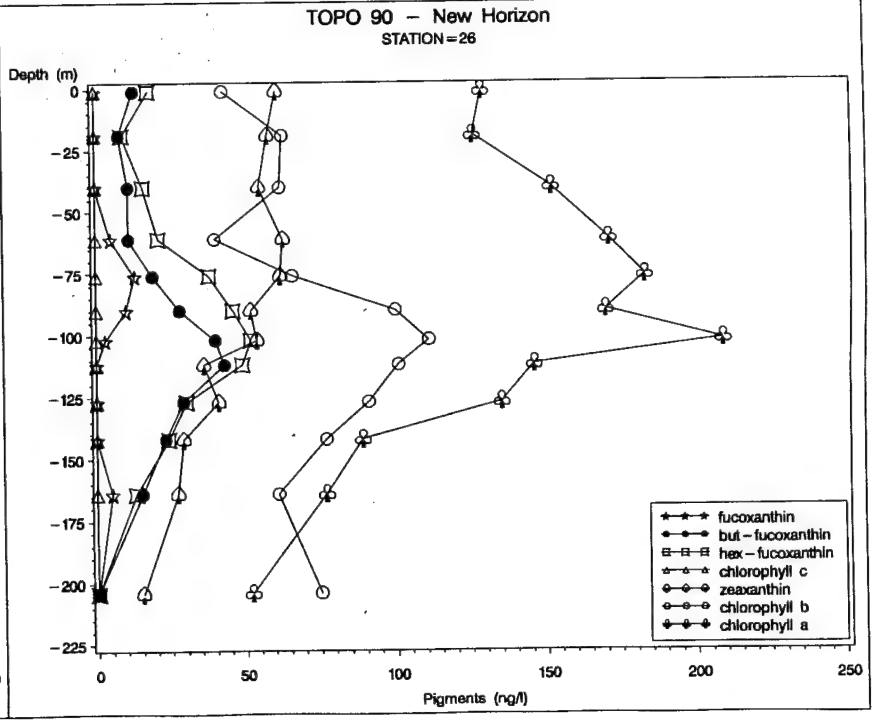

TOPO 90 – New Horizon
STATION=19
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

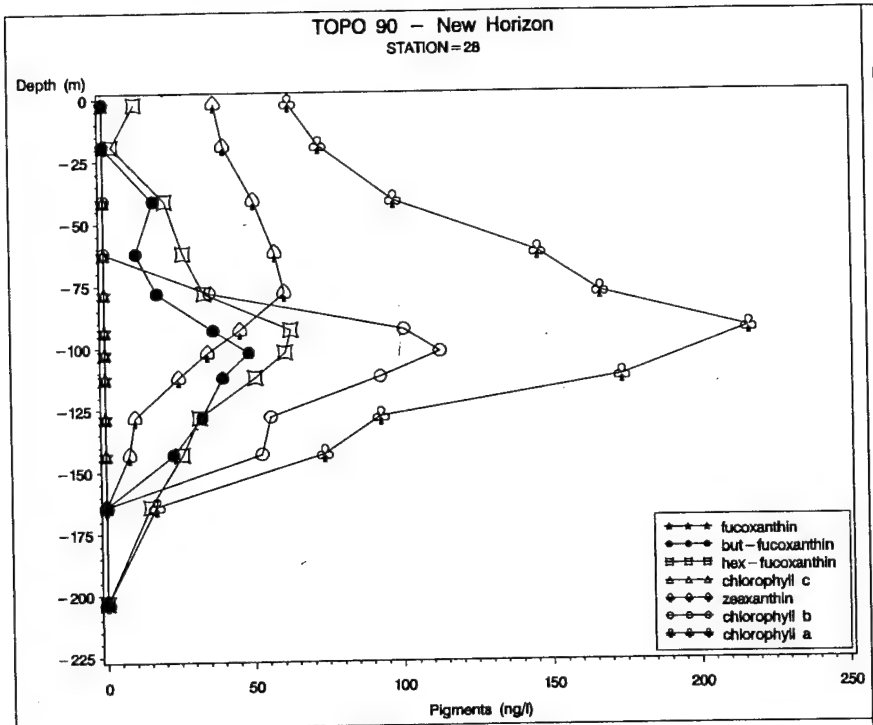

TOPO 90 – New Horizon
STATION=22
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

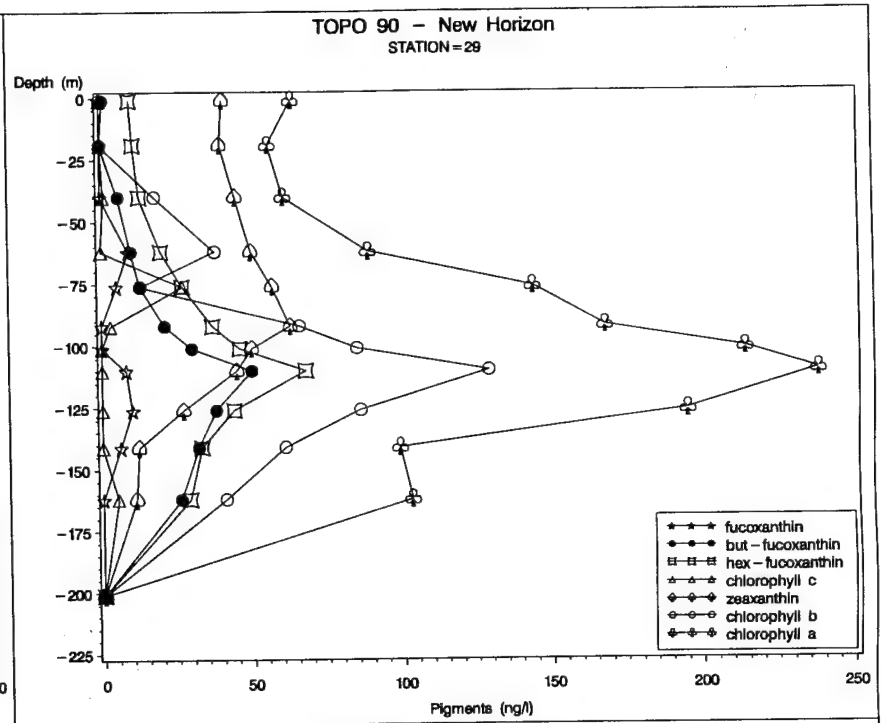

TOPO 90 – New Horizon
STATION=24
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

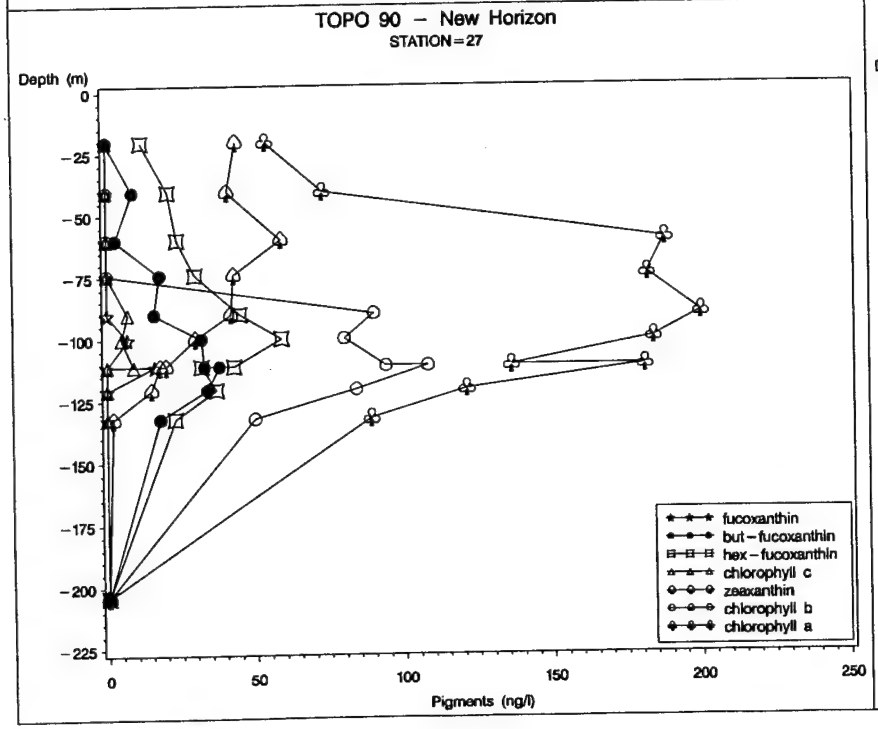

TOPO 90 – New Horizon
STATION=25
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

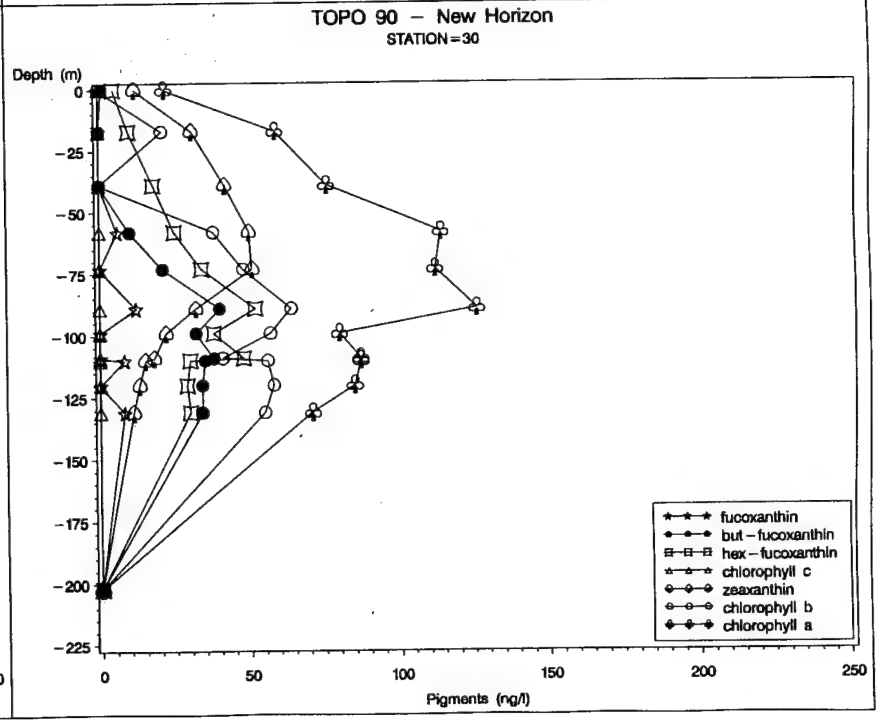

TOPO 90 – New Horizon
STATION=23
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

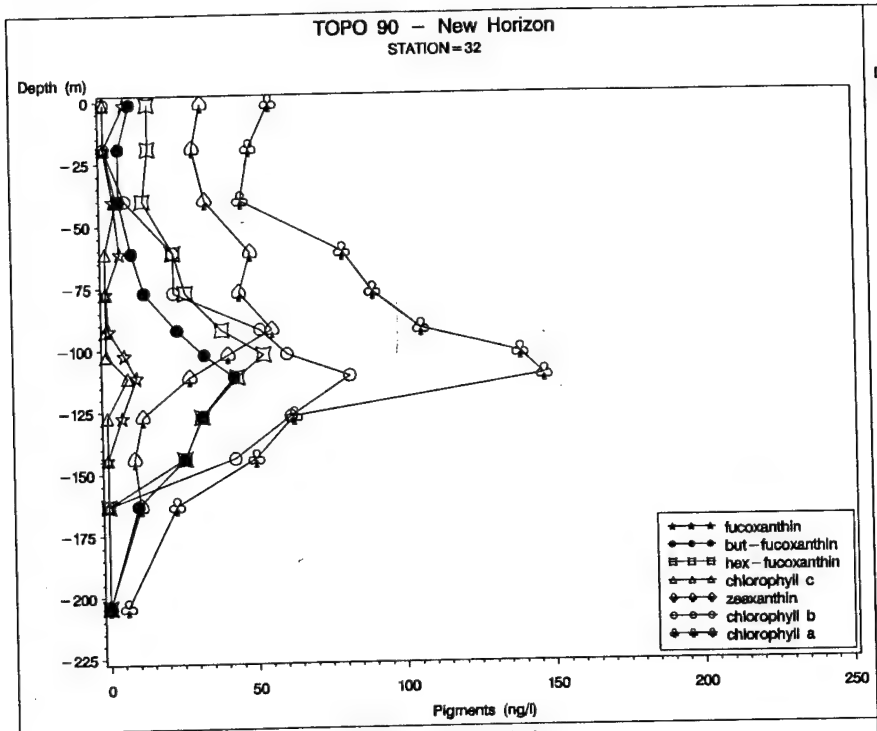

TOPO 90 – New Horizon
STATION=26
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

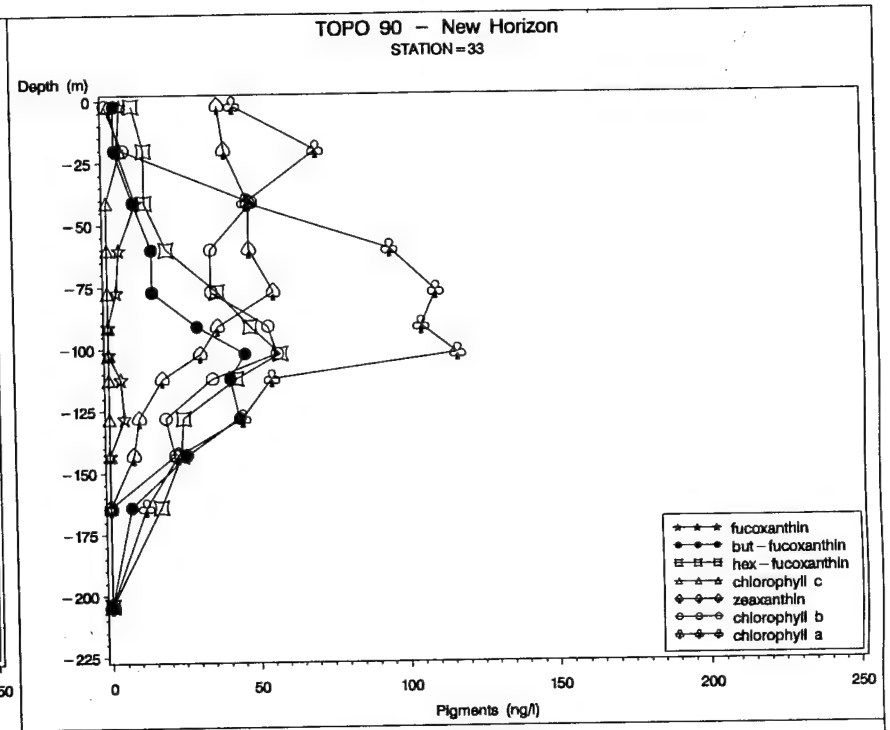

TOPO 90 – New Horizon
STATION=28
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

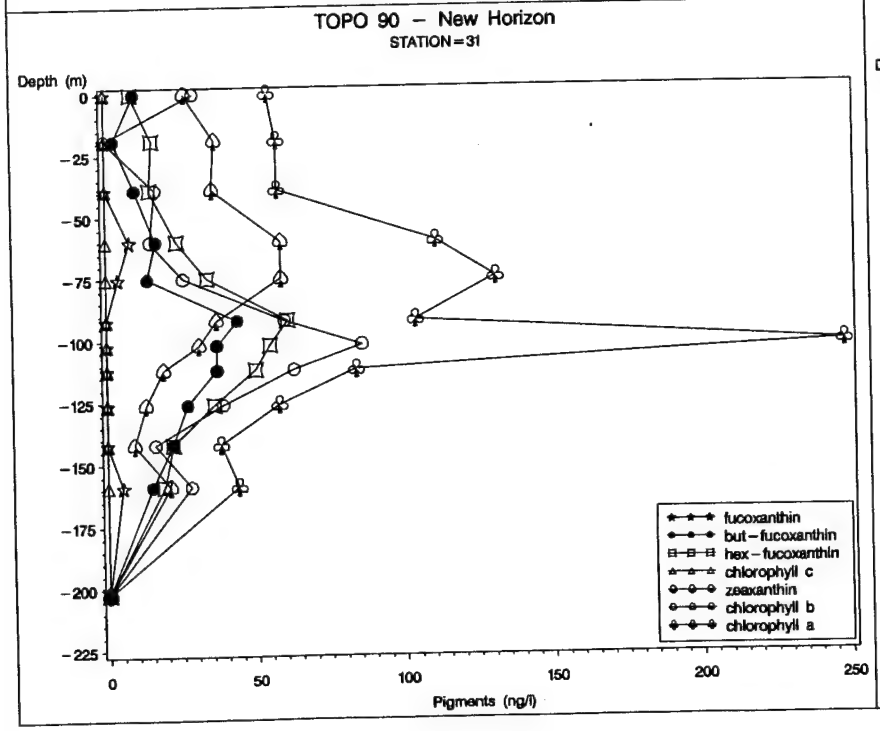

TOPO 90 – New Horizon
STATION=29
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

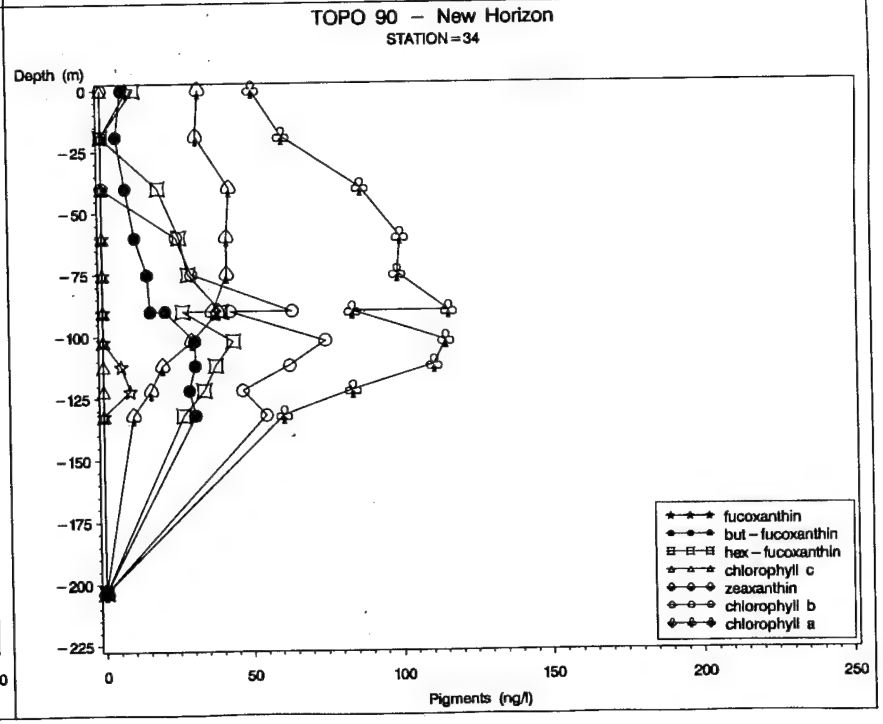

TOPO 90 – New Horizon
STATION=27
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

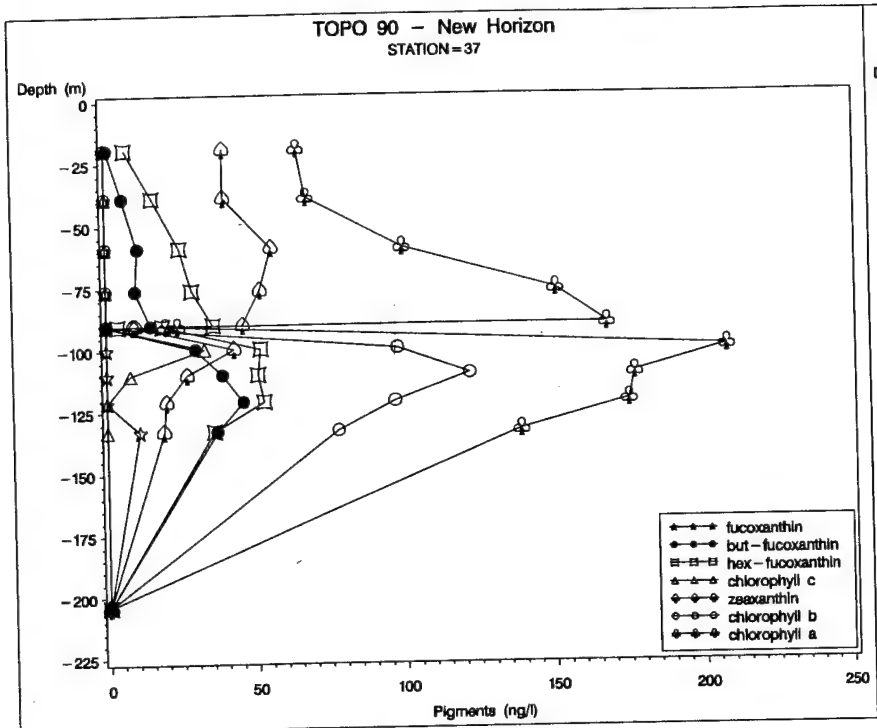

TOPO 90 – New Horizon
STATION=30
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

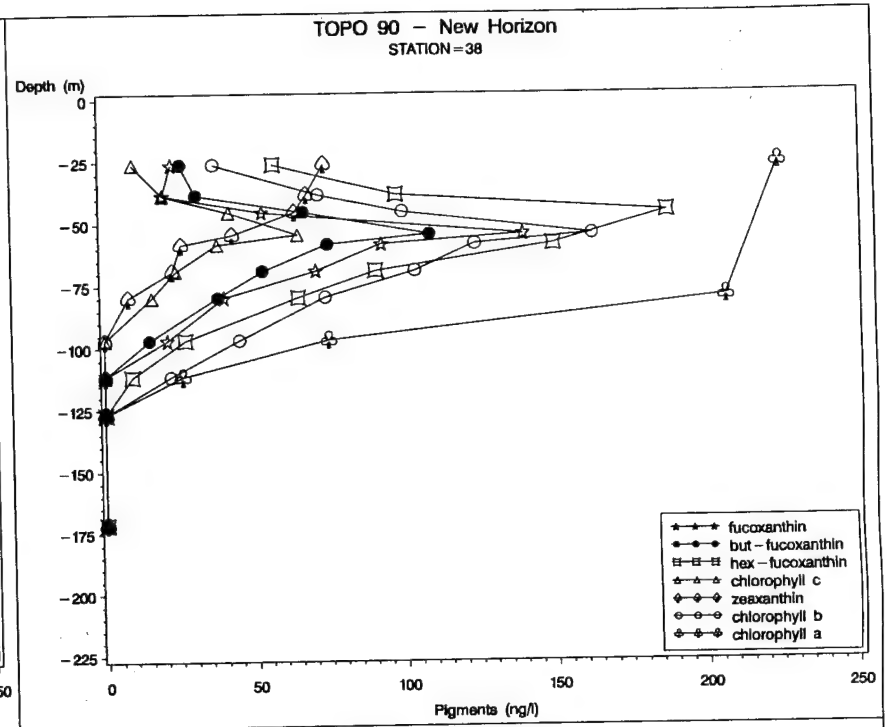

TOPO 90 – New Horizon
STATION=32
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

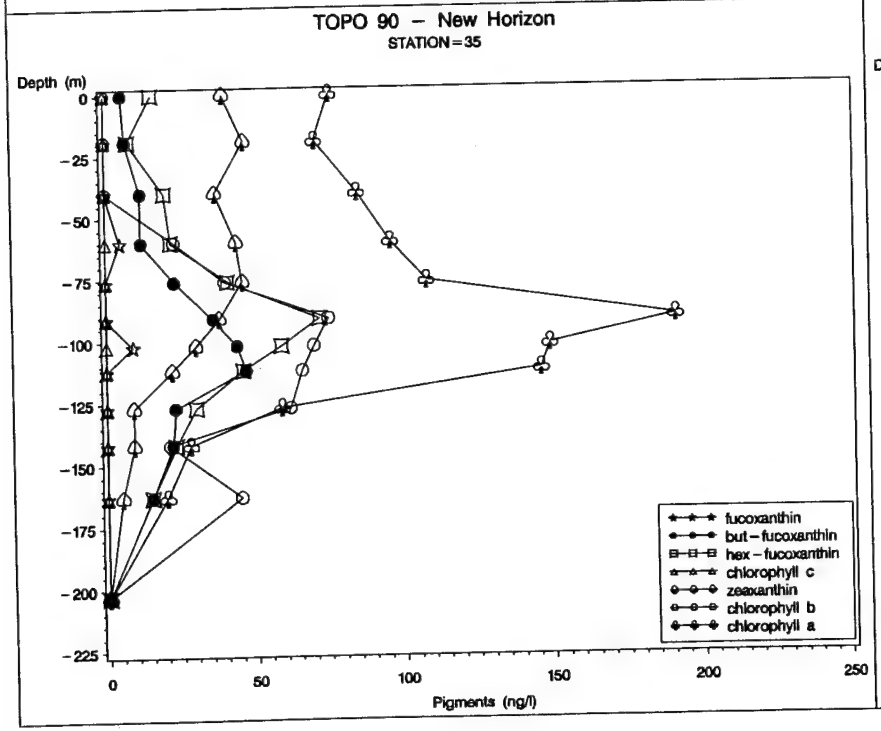

TOPO 90 – New Horizon
STATION=33
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

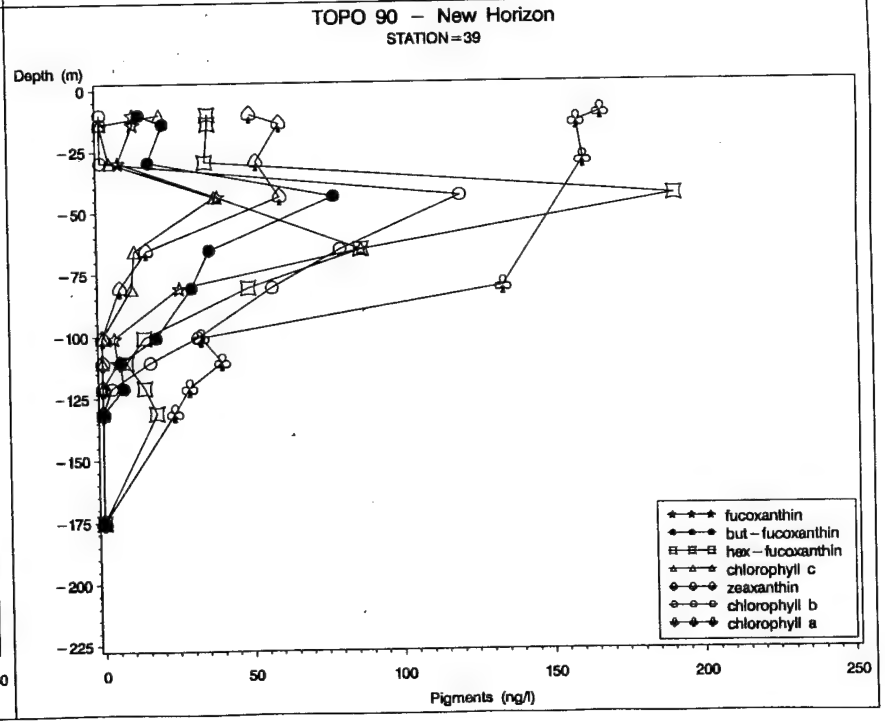

TOPO 90 – New Horizon
STATION=31
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

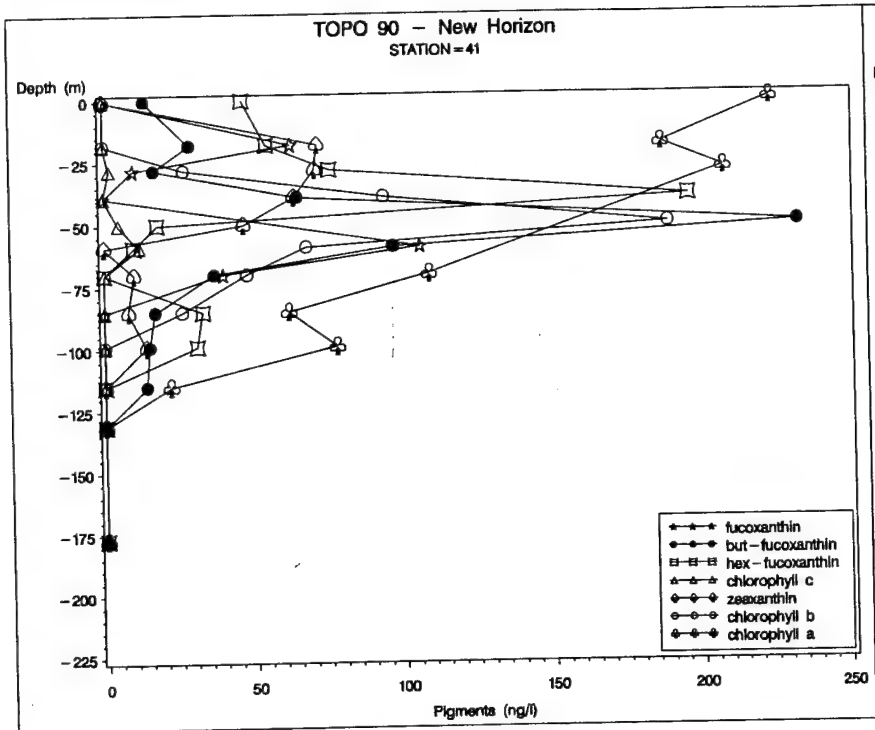

TOPO 90 – New Horizon
STATION=34
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

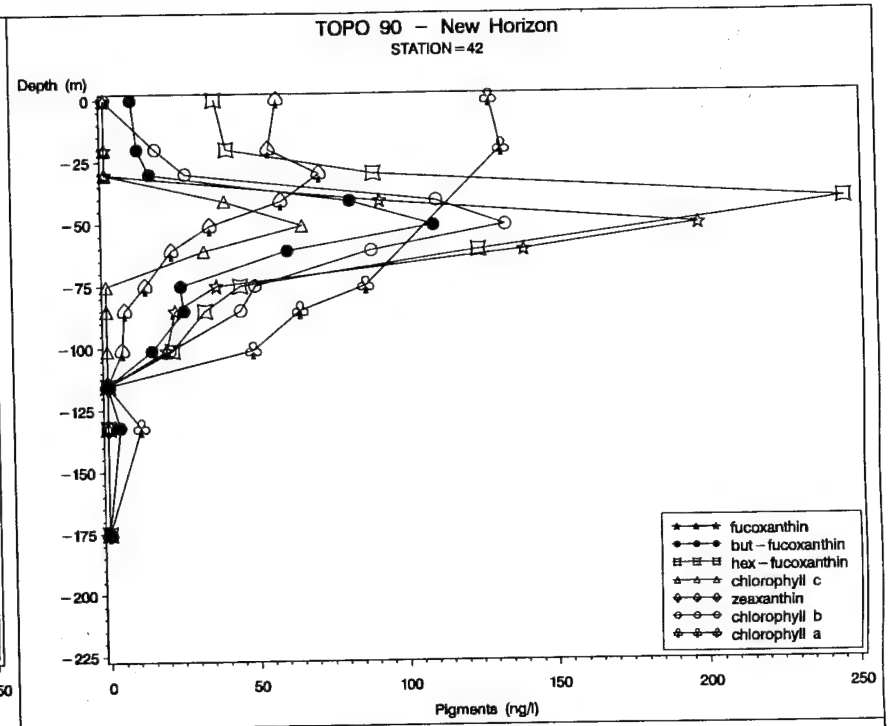

TOPO 90 – New Horizon
STATION=37
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

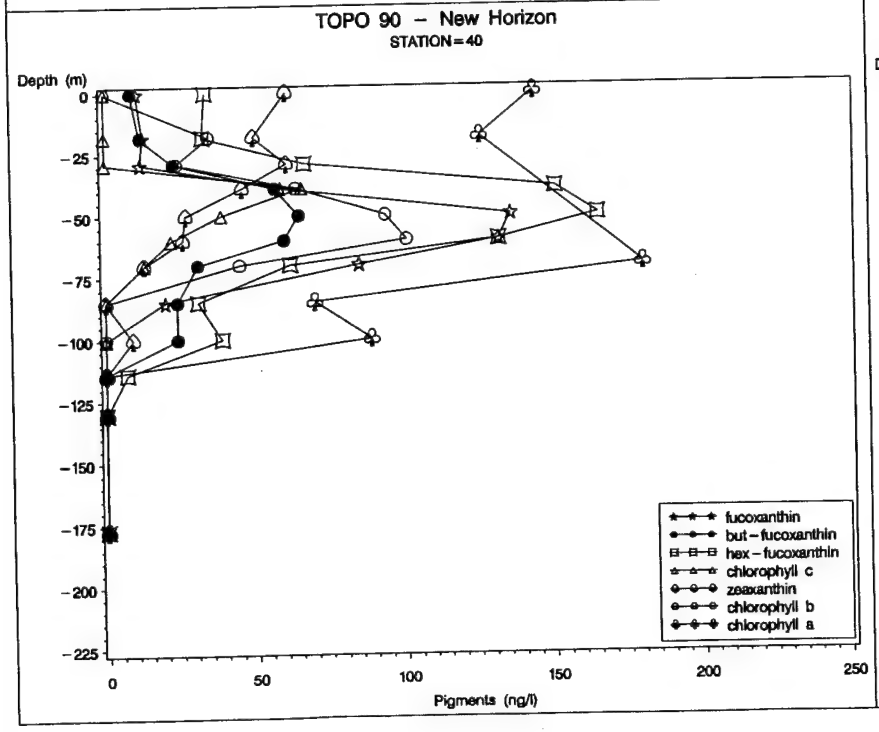

TOPO 90 – New Horizon
STATION=38
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

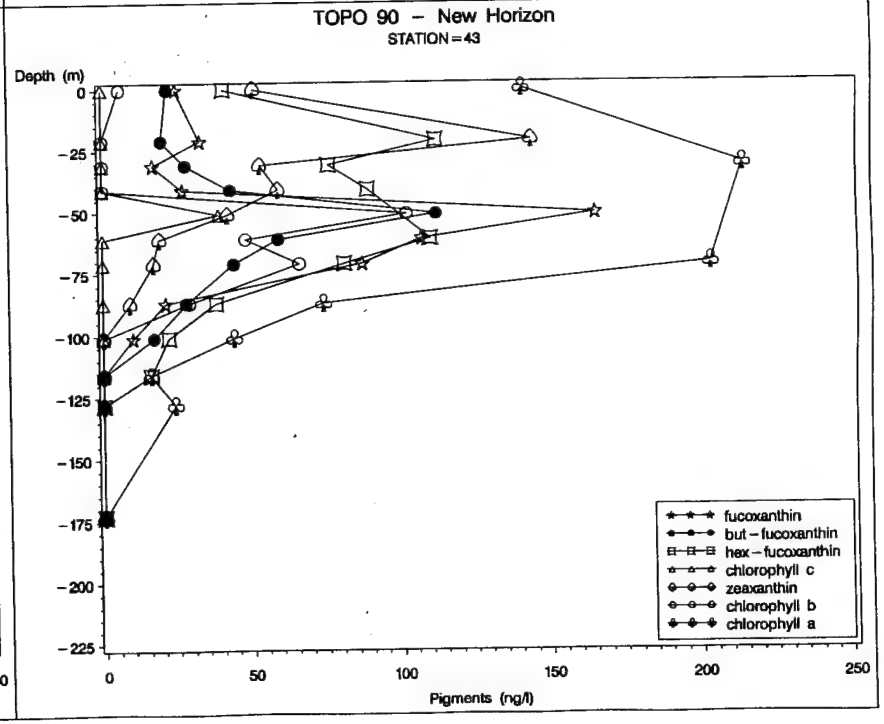

TOPO 90 – New Horizon
STATION=35
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

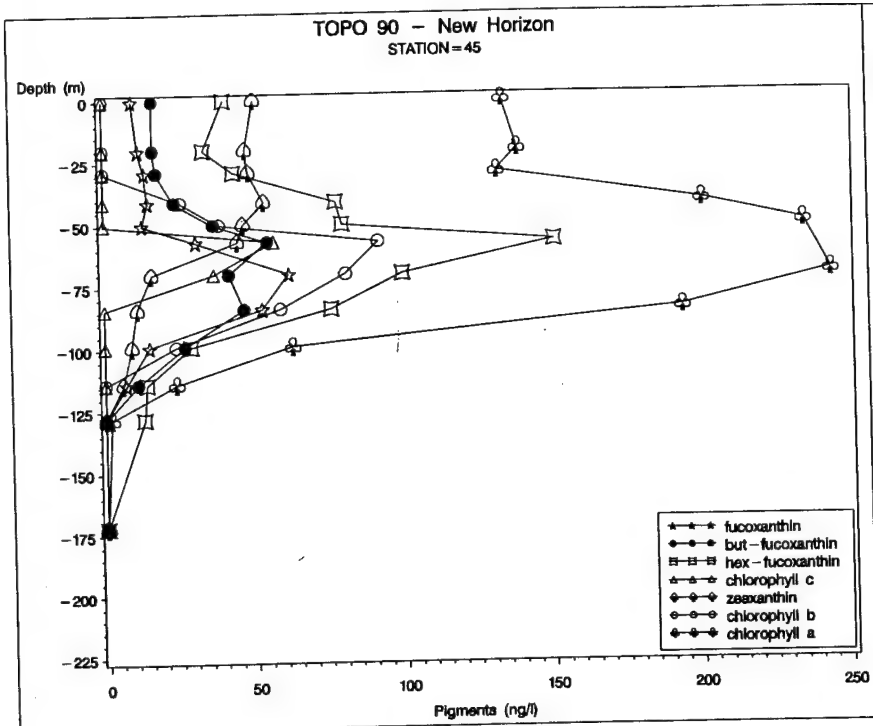

TOPO 90 – New Horizon
STATION=39
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

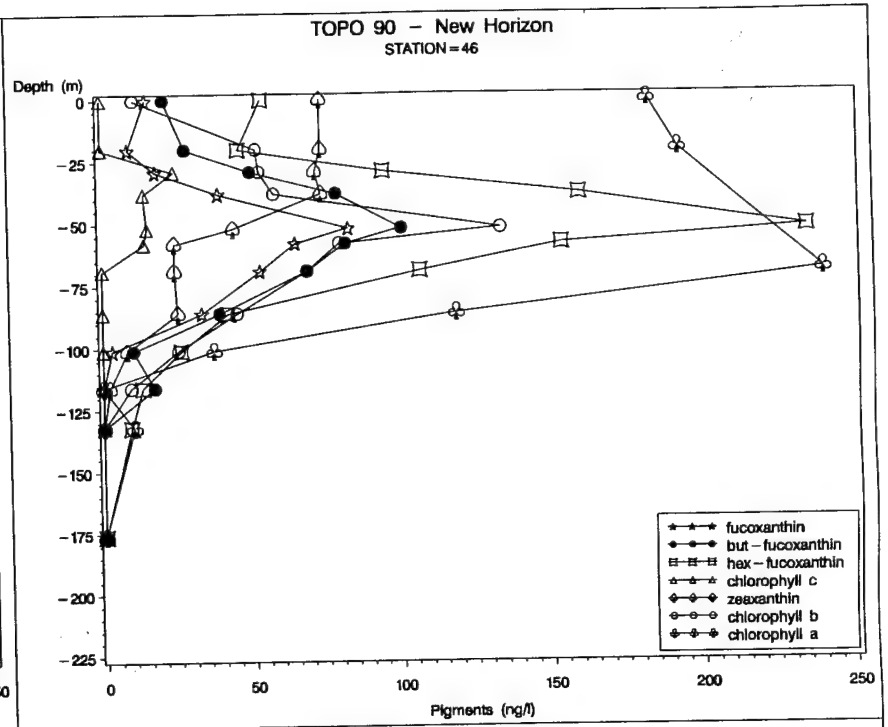

TOPO 90 – New Horizon
STATION=41
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

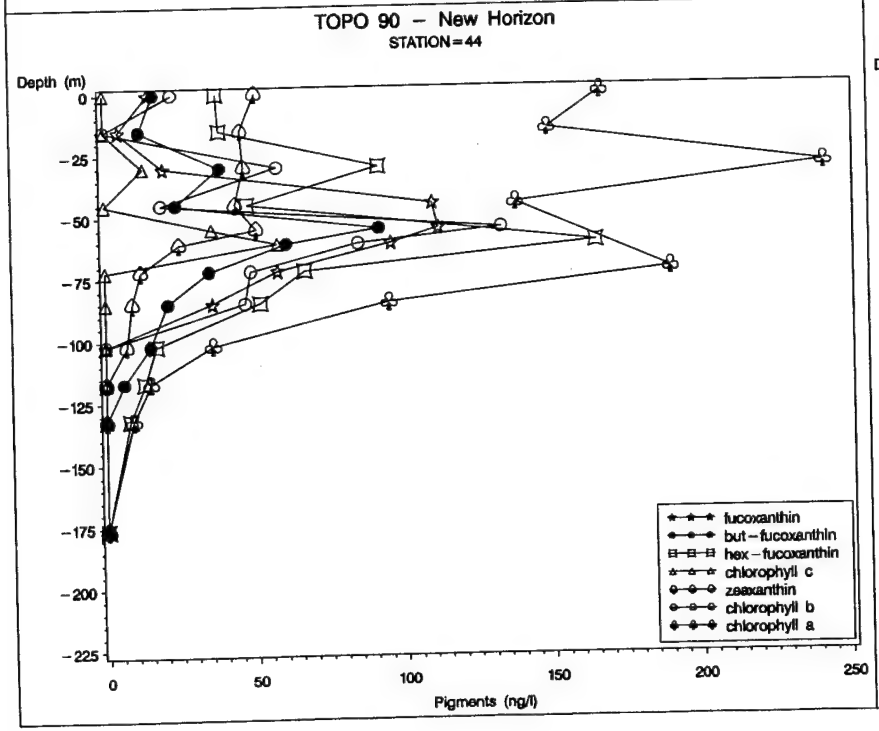

TOPO 90 – New Horizon
STATION=42
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

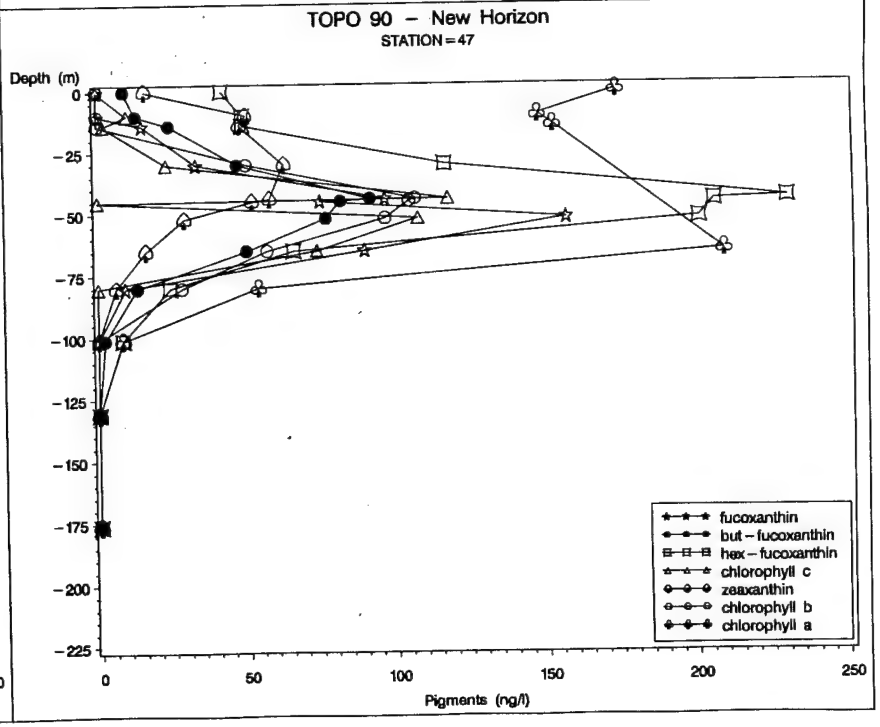

TOPO 90 – New Horizon
STATION=40
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

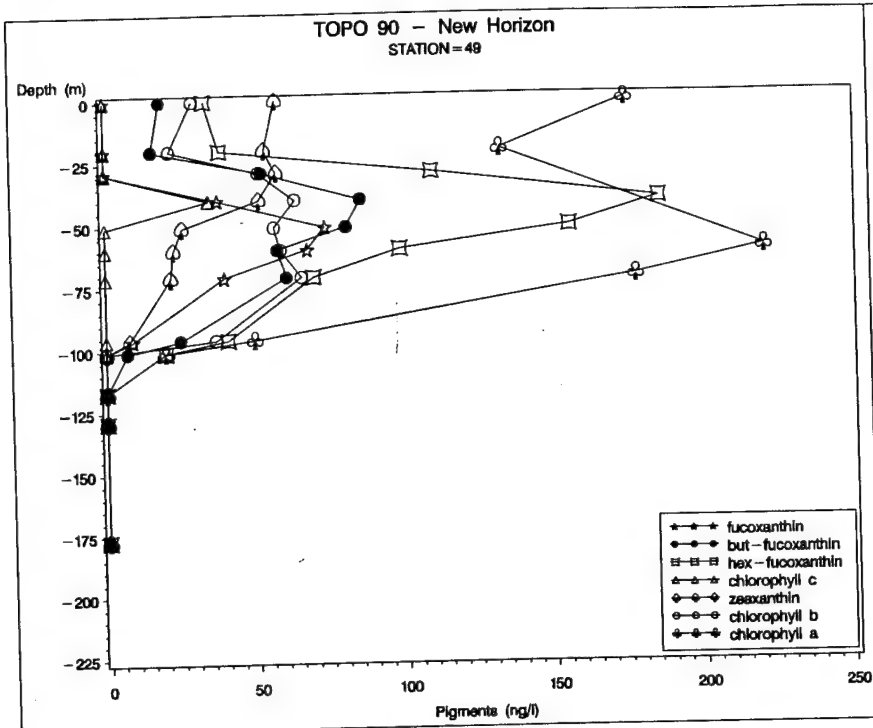

TOPO 90 – New Horizon
STATION=43
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

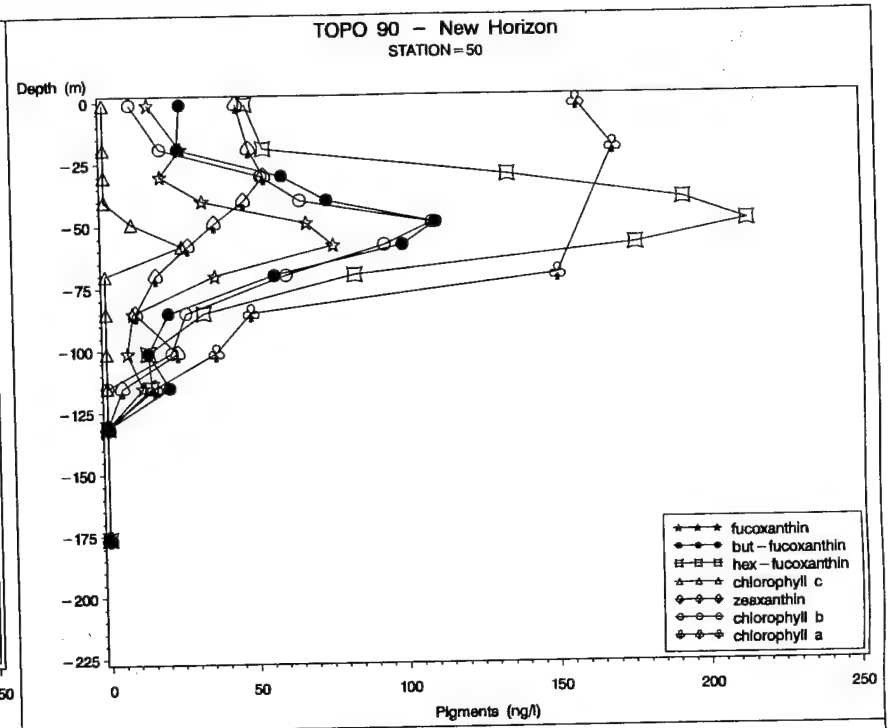

TOPO 90 – New Horizon
STATION=45
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

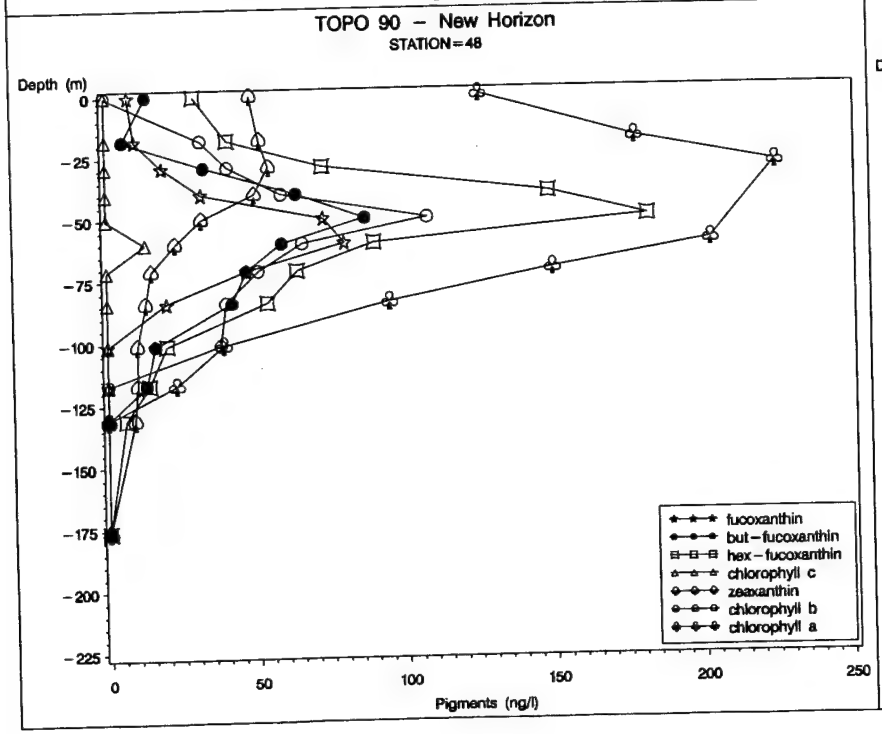

TOPO 90 – New Horizon
STATION=46
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

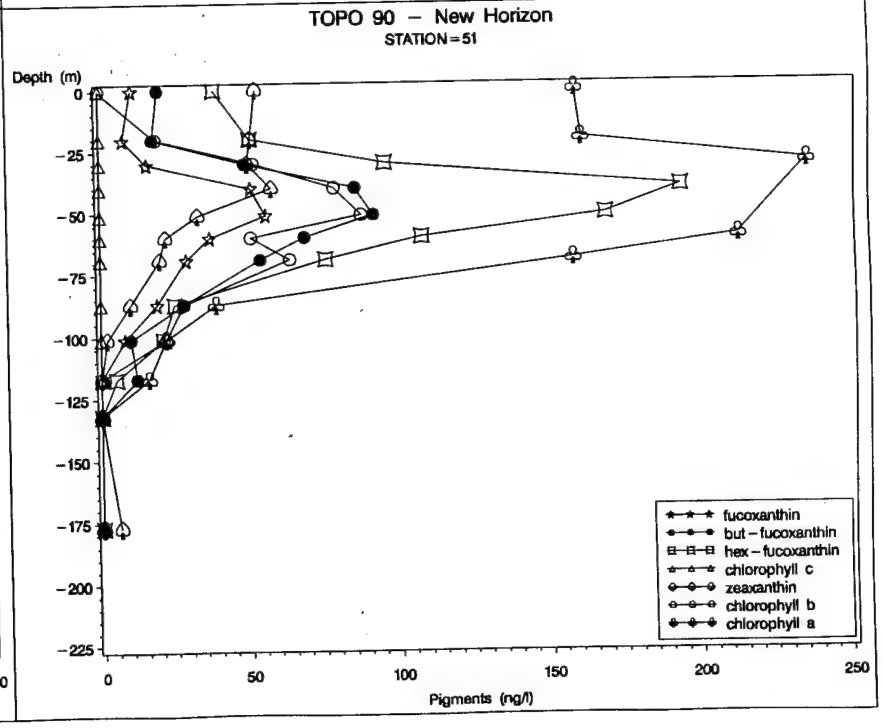

TOPO 90 – New Horizon
STATION=44
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

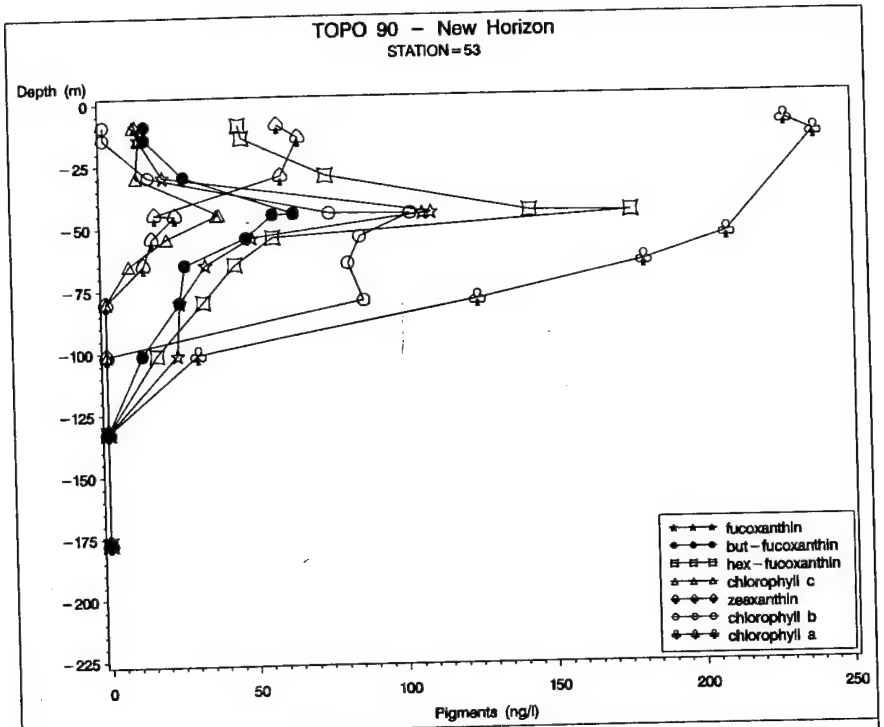

TOPO 90 – New Horizon
STATION=47
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

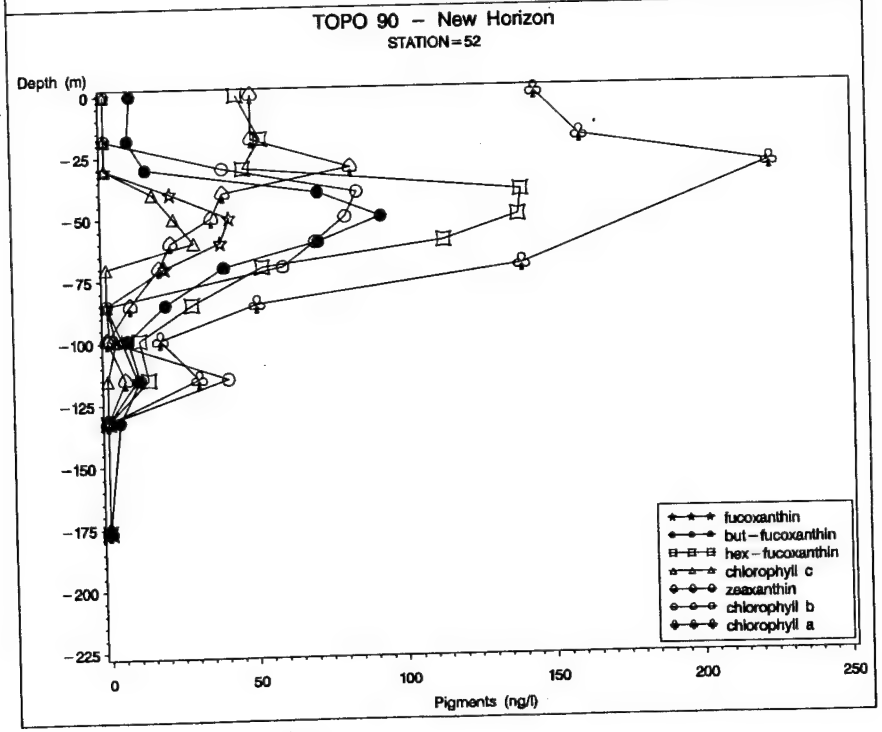

TOPO 90 – New Horizon
STATION=49
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

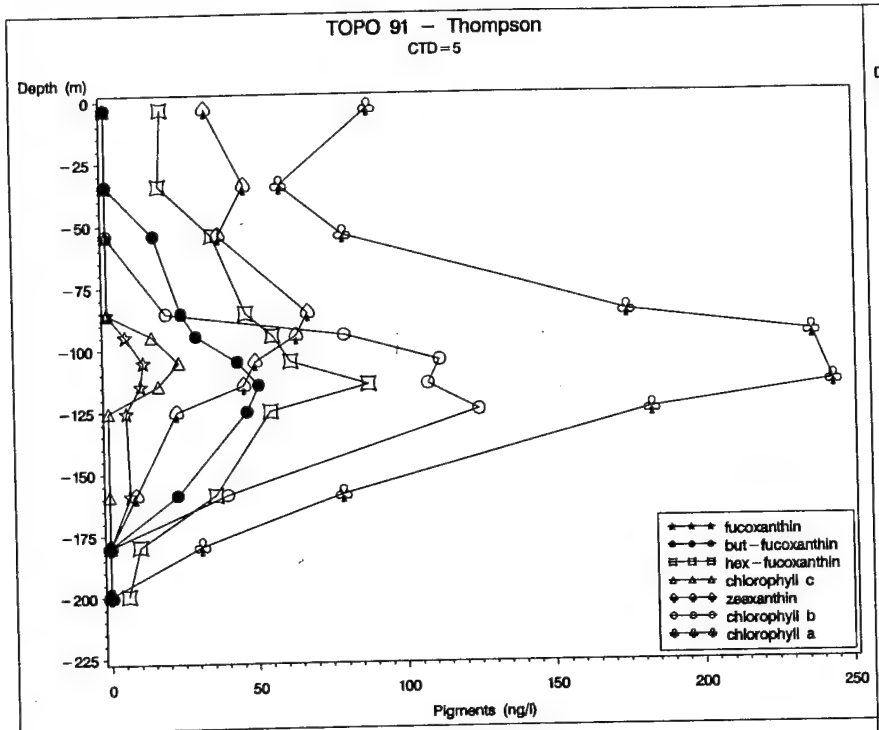

TOPO 90 – New Horizon
STATION=50
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

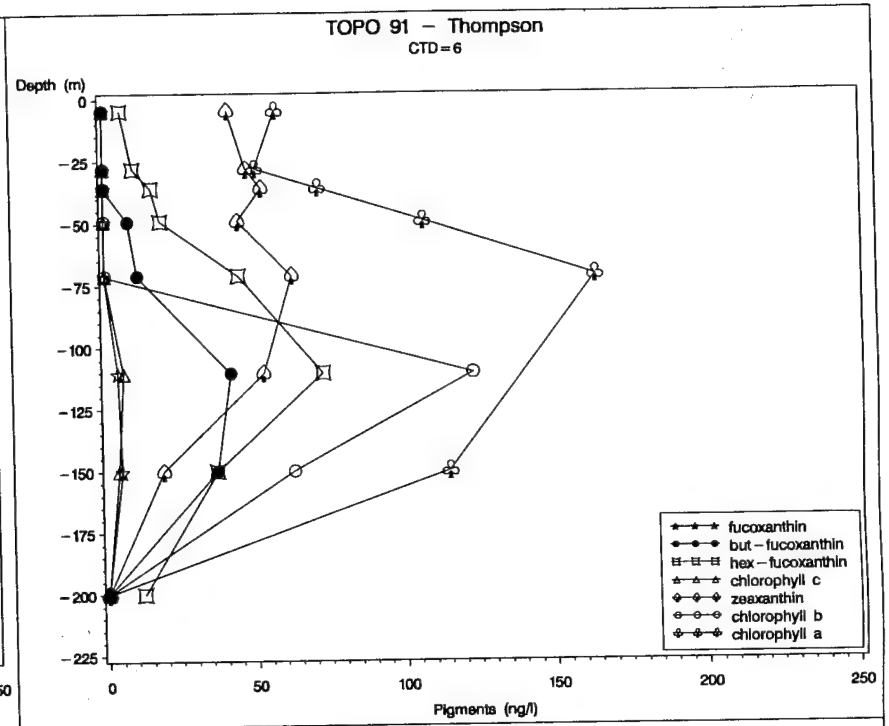

TOPO 90 – New Horizon
STATION=48
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

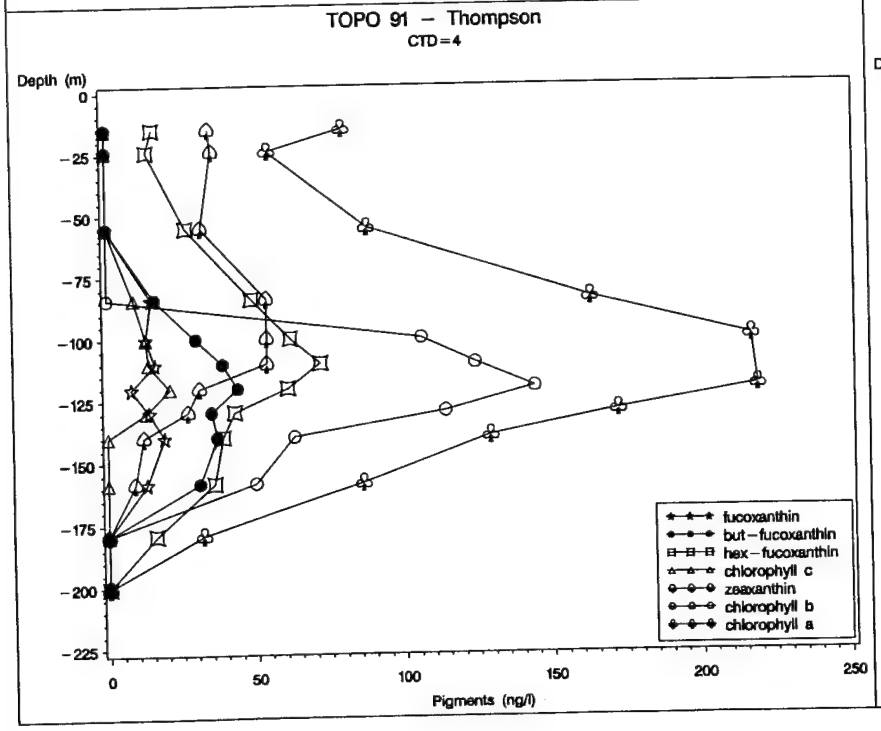

TOPO 90 – New Horizon
STATION=51
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

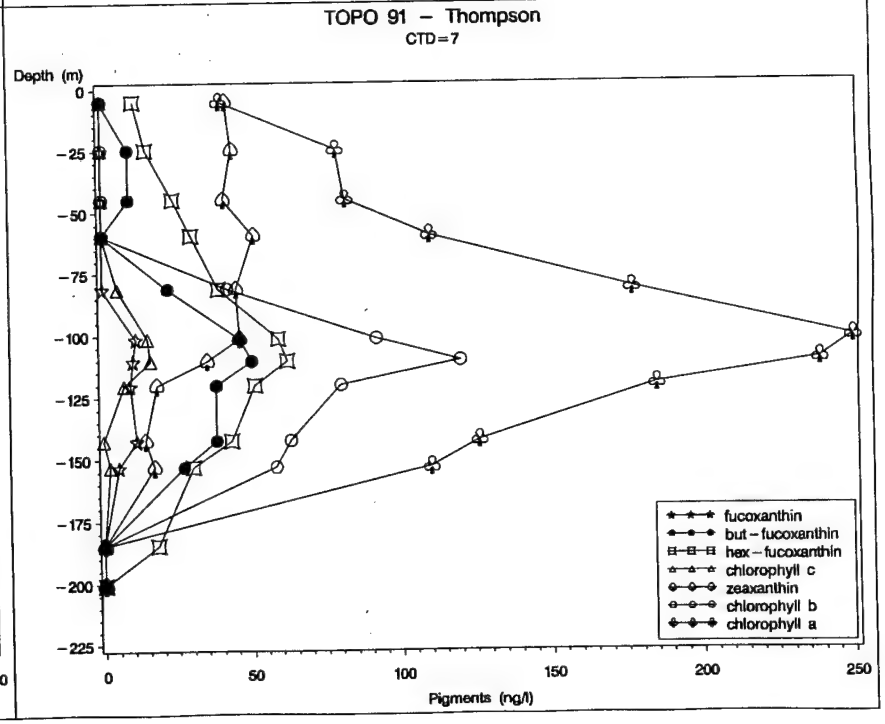

TOPO 90 – New Horizon
STATION=53
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

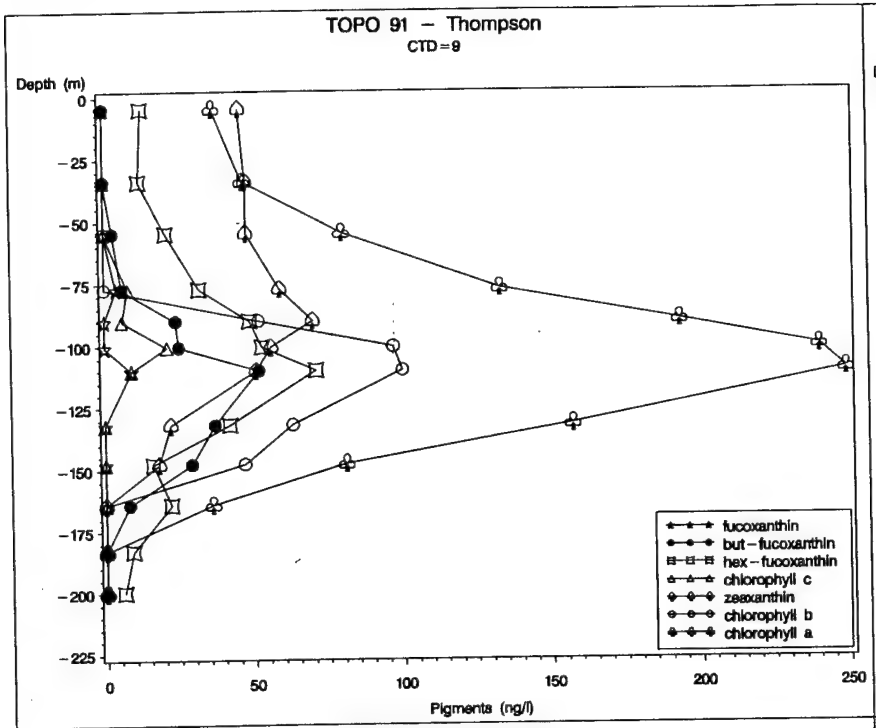

TOPO 90 – New Horizon
STATION=52
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

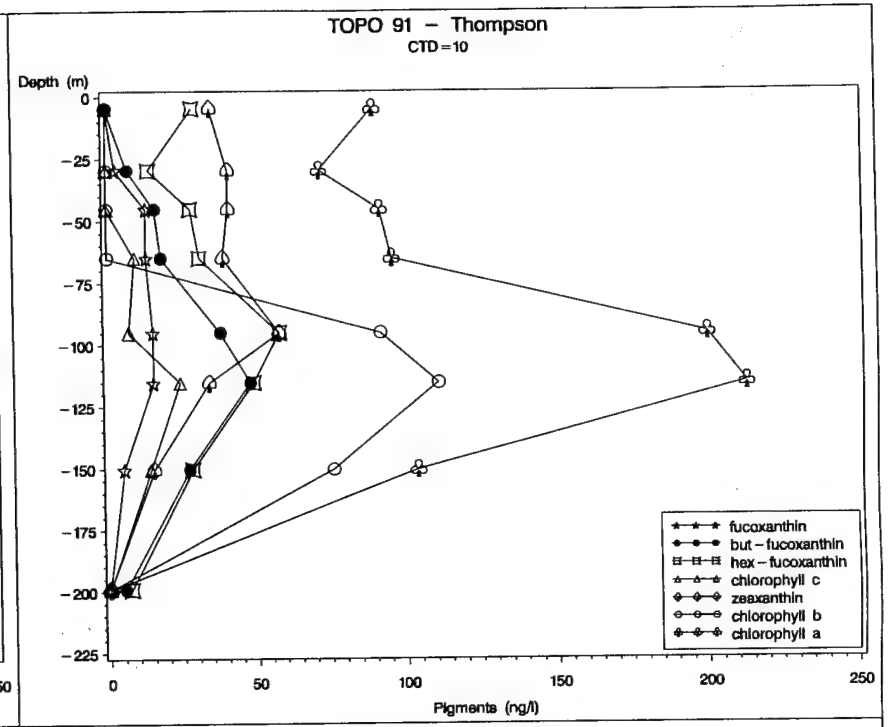

TOPO 91 – Thompson
CTD=5
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

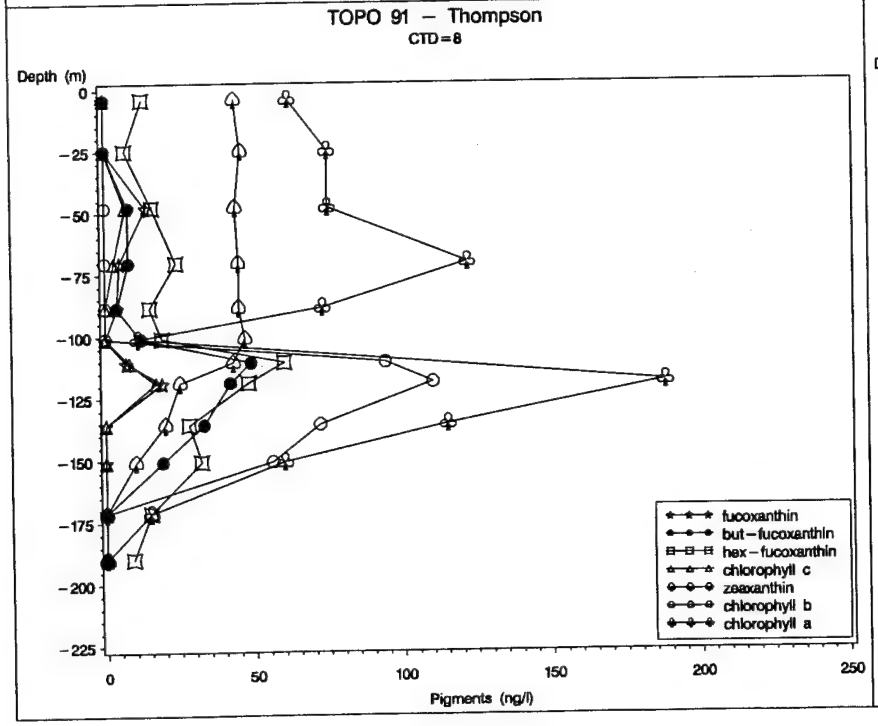

TOPO 91 – Thompson
CTD=6
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

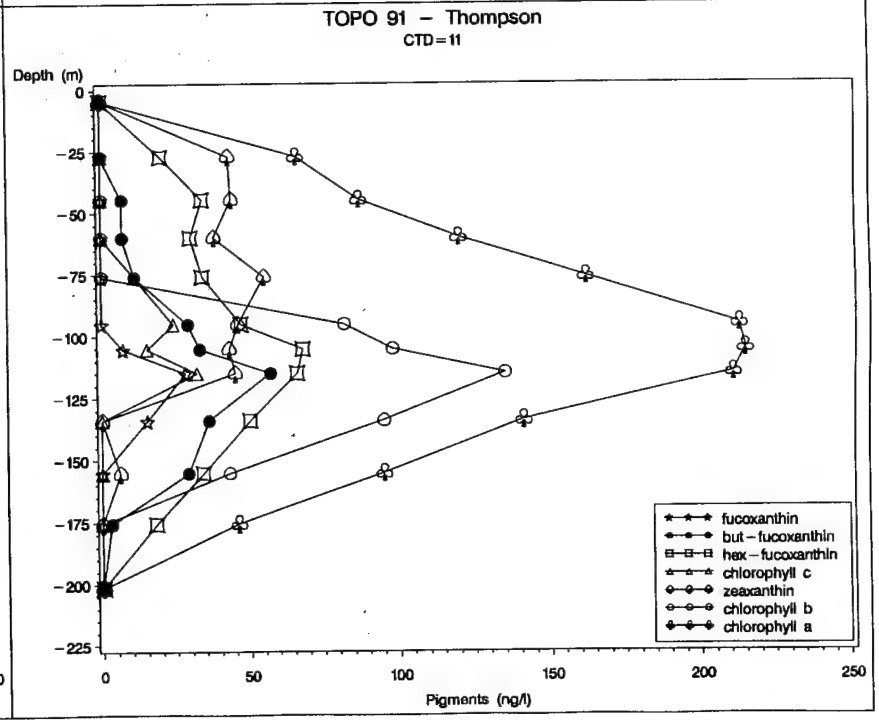

TOPO 91 – Thompson
CTD=4
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

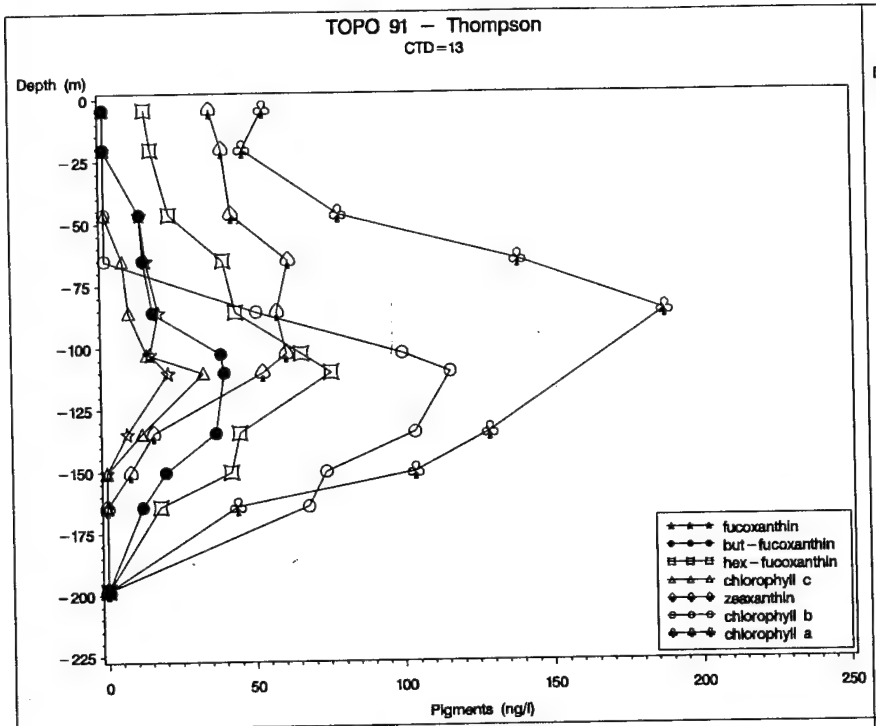

TOPO 91 – Thompson
CTD=7
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

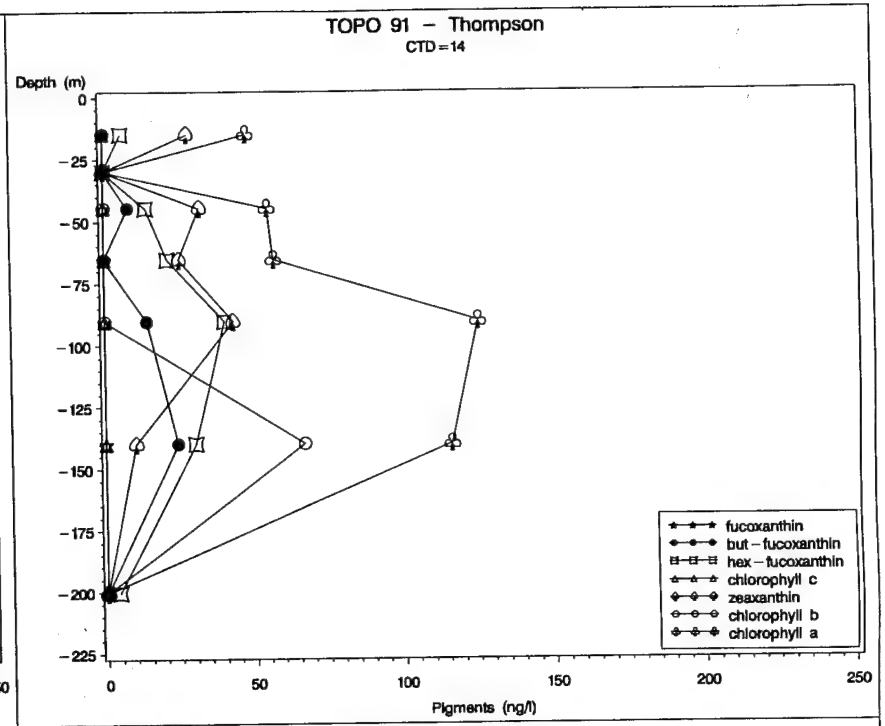

TOPO 91 – Thompson
CTD=9
Depth (m)
0
−25
−50
−75
−100
−125
−150
−175
−200
−225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but–fucoxanthin
hex–fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

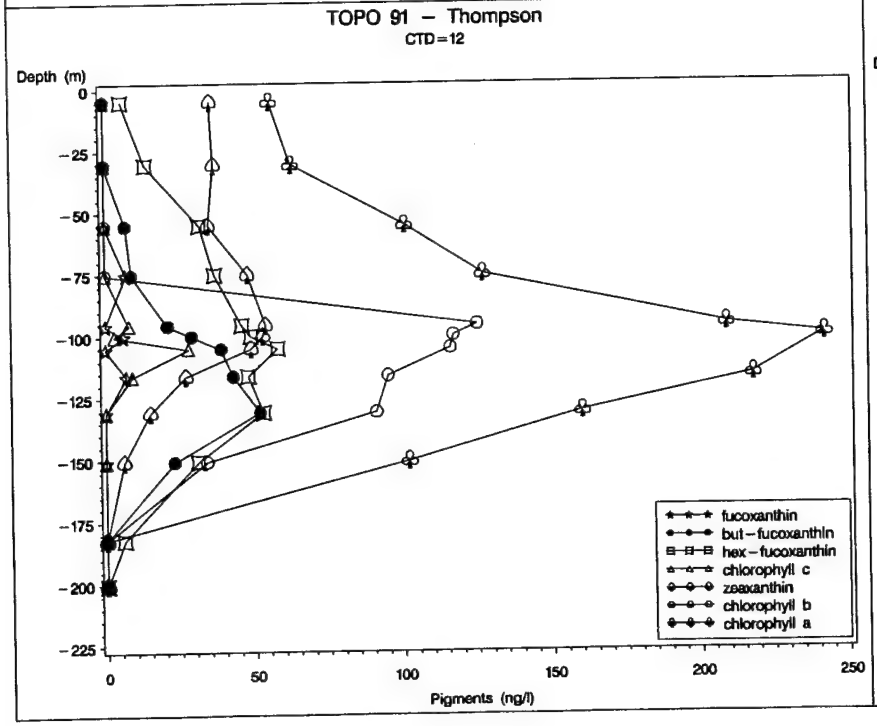

TOPO 91 – Thompson
CTD=10
Depth (m)
0
−25
−50
−75
−100
−125
−150
−175
−200
−225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but–fucoxanthin
hex–fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

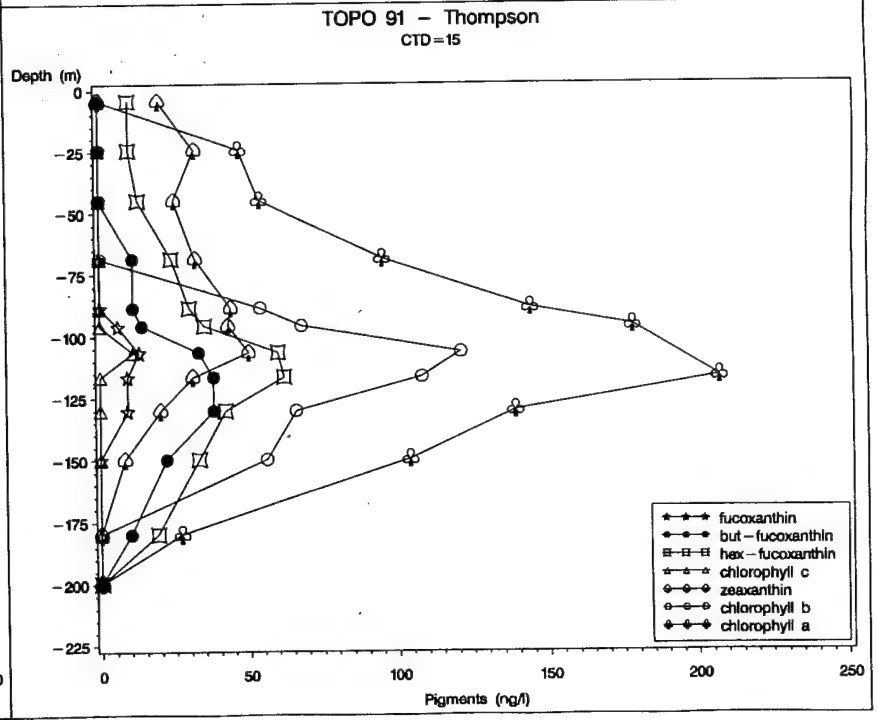

TOPO 91 – Thompson
CTD=8
Depth (m)
0
−25
−50
−75
−100
−125
−150
−175
−200
−225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but–fucoxanthin
hex–fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

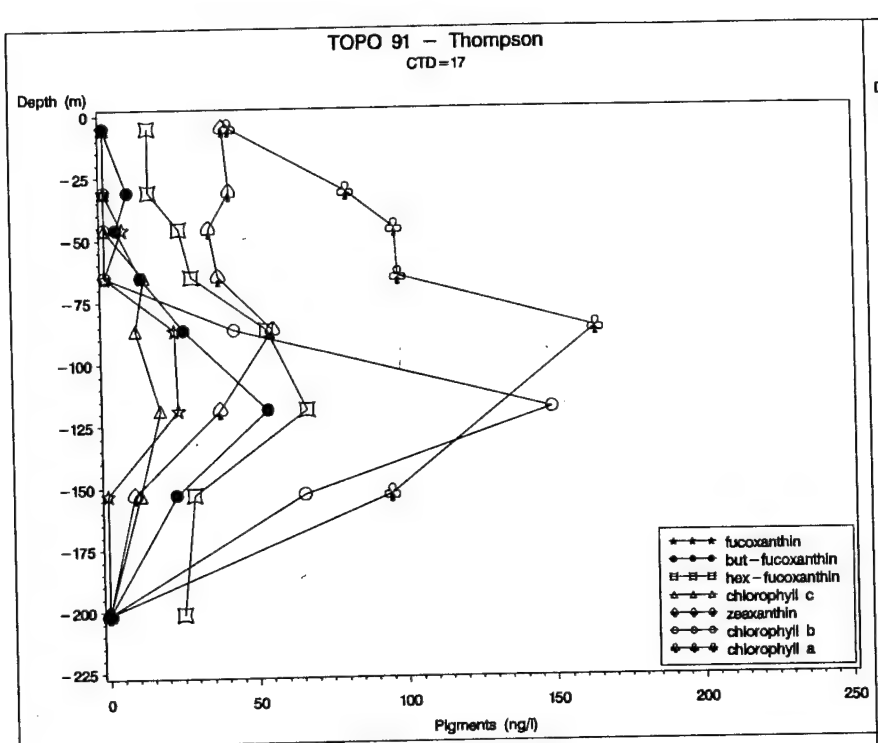

TOPO 91 – Thompson
CTD=11
Depth (m)
0
−25
−50
−75
−100
−125
−150
−175
−200
−225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but–fucoxanthin
hex–fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

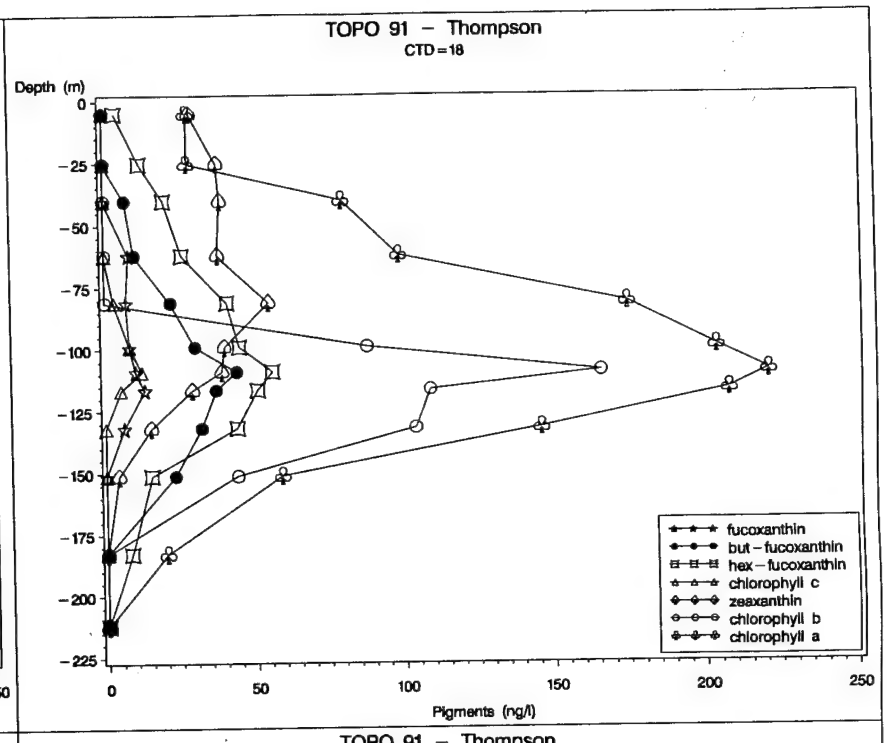

TOPO 91 – Thompson
CTD=13
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

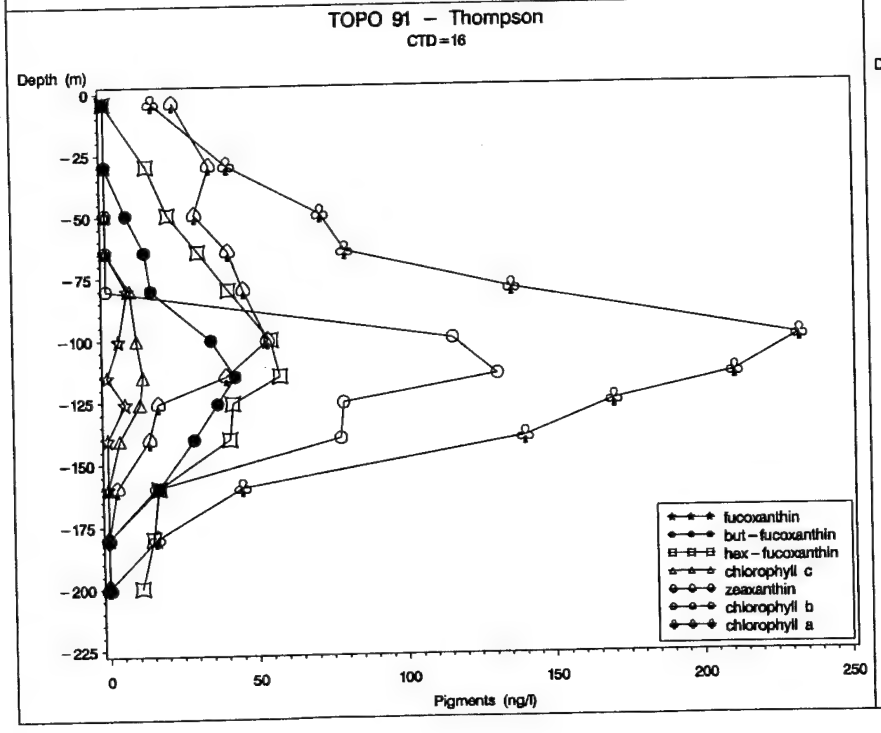

TOPO 91 – Thompson
CTD=14
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

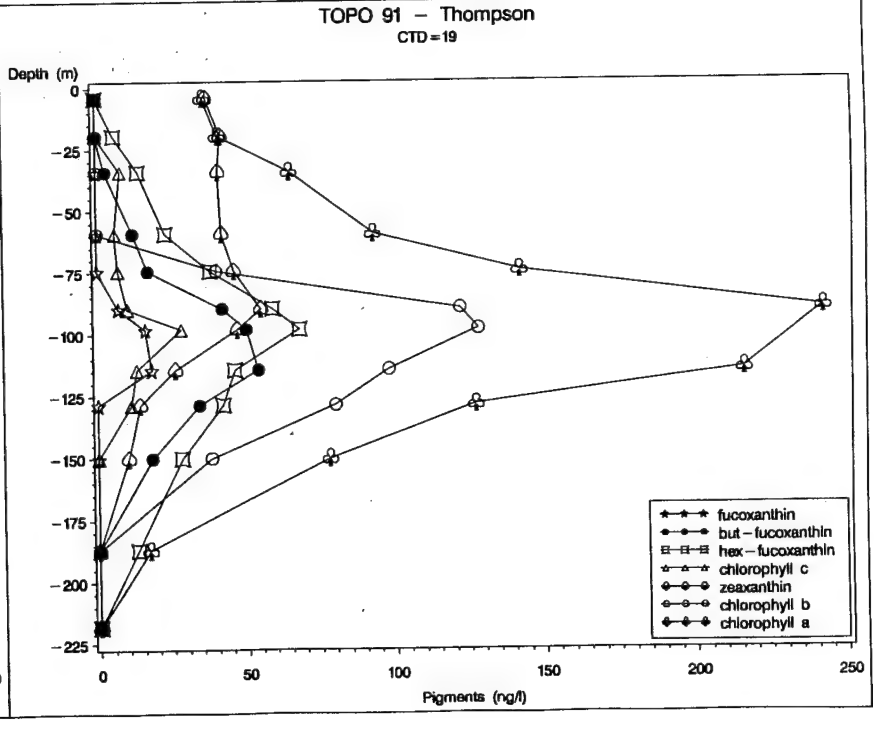

TOPO 91 – Thompson
CTD=12
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

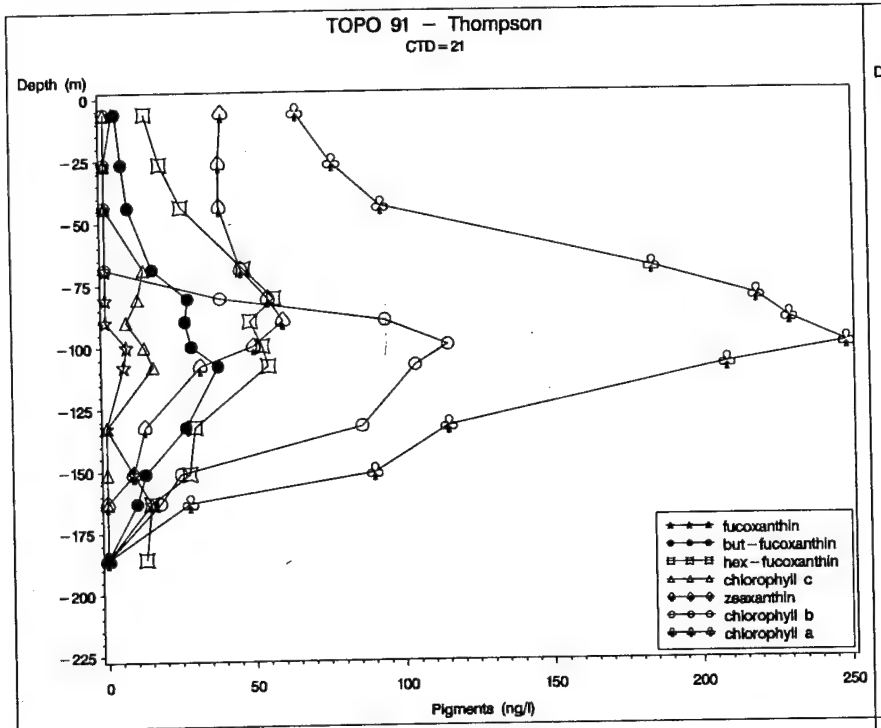

TOPO 91 – Thompson
CTD=15
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

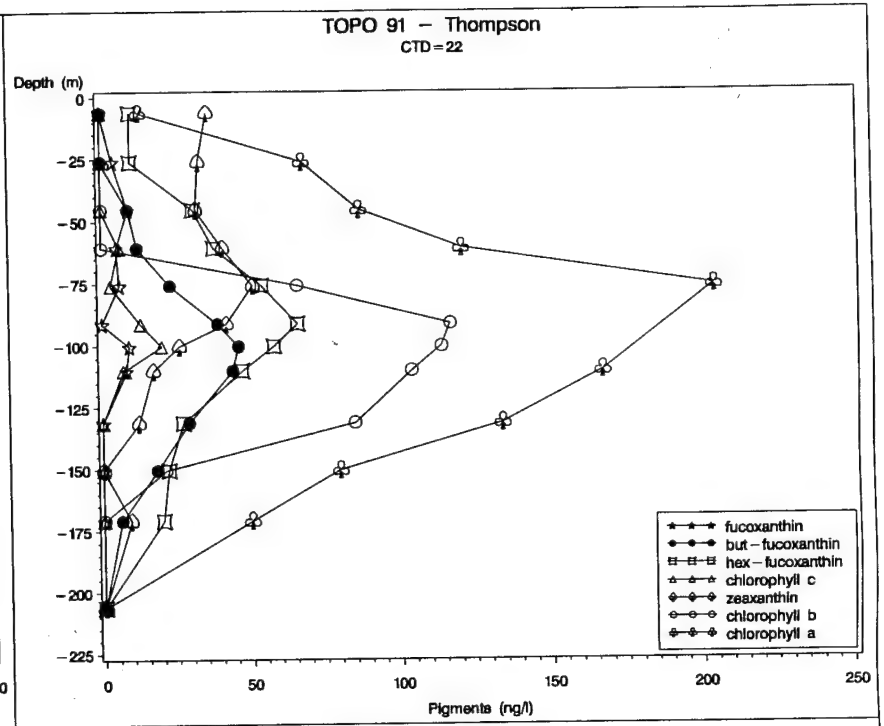

TOPO 91 – Thompson
CTD=17
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

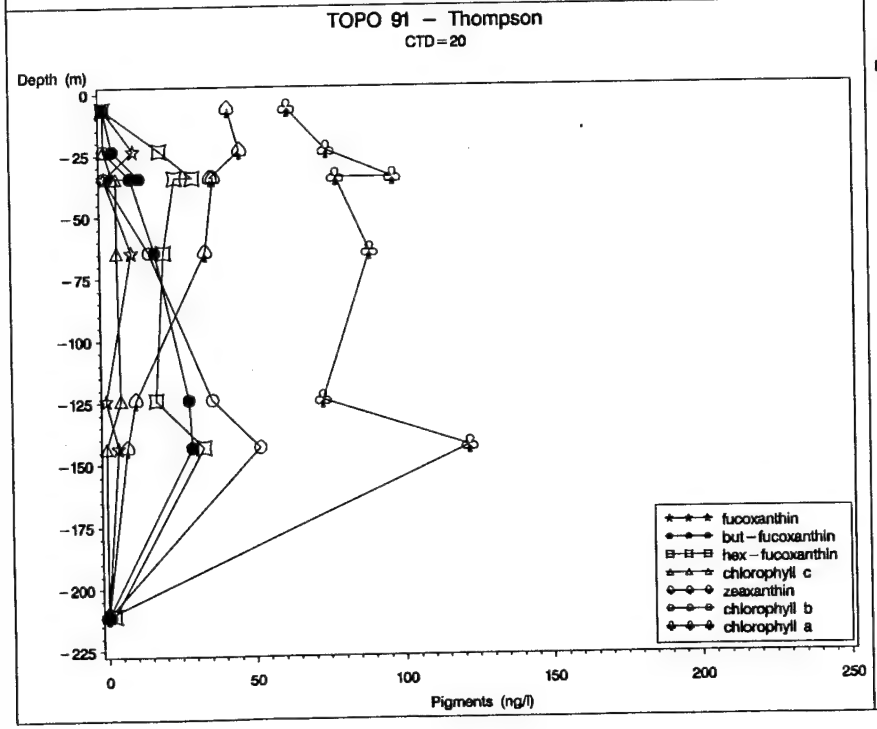

TOPO 91 – Thompson
CTD=18
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

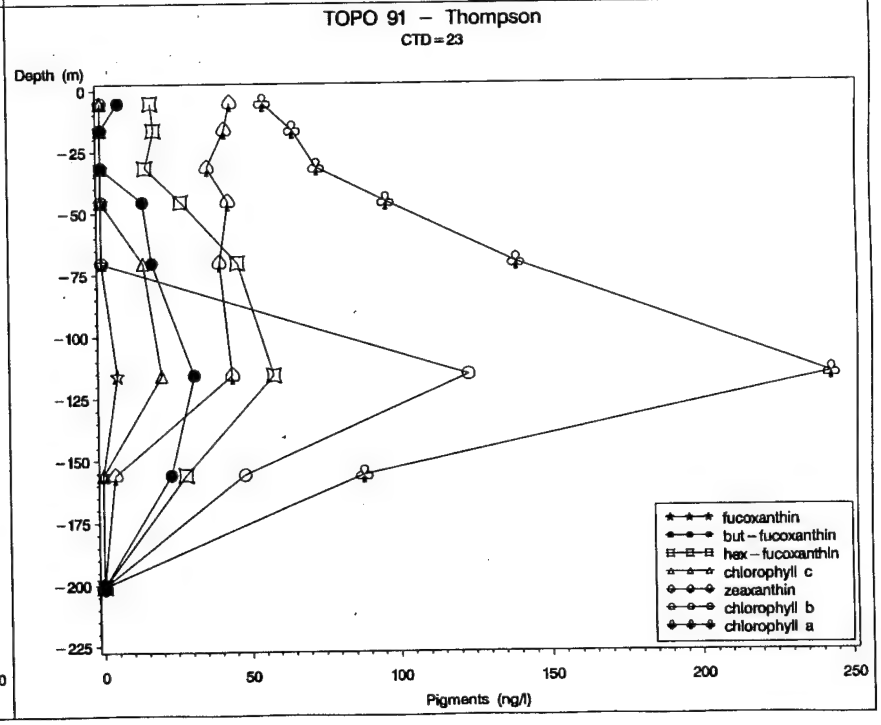

TOPO 91 – Thompson
CTD=16
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

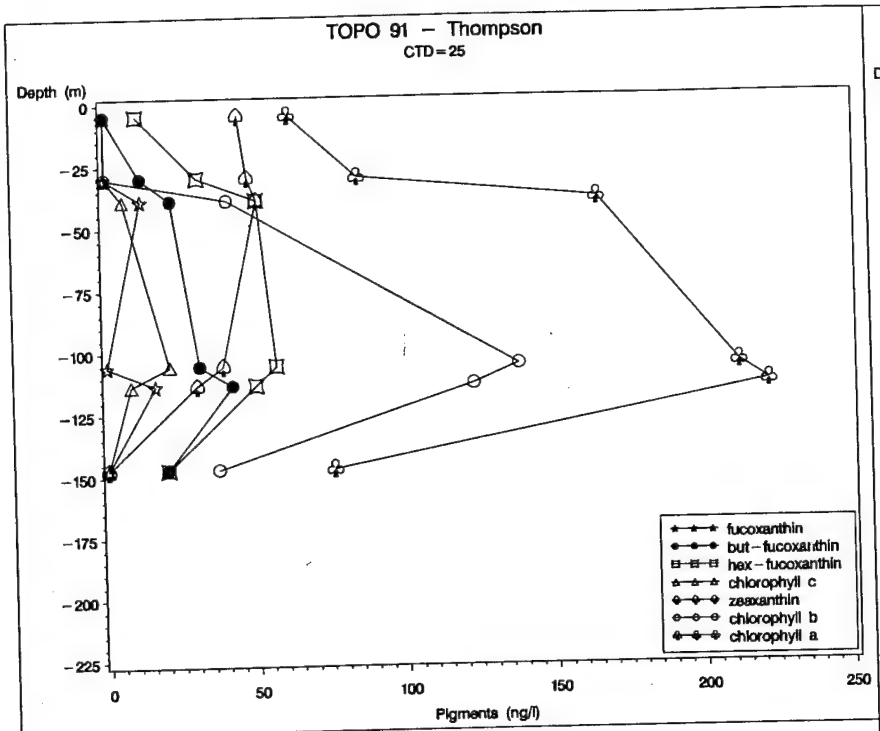

TOPO 91 – Thompson
CTD=19
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

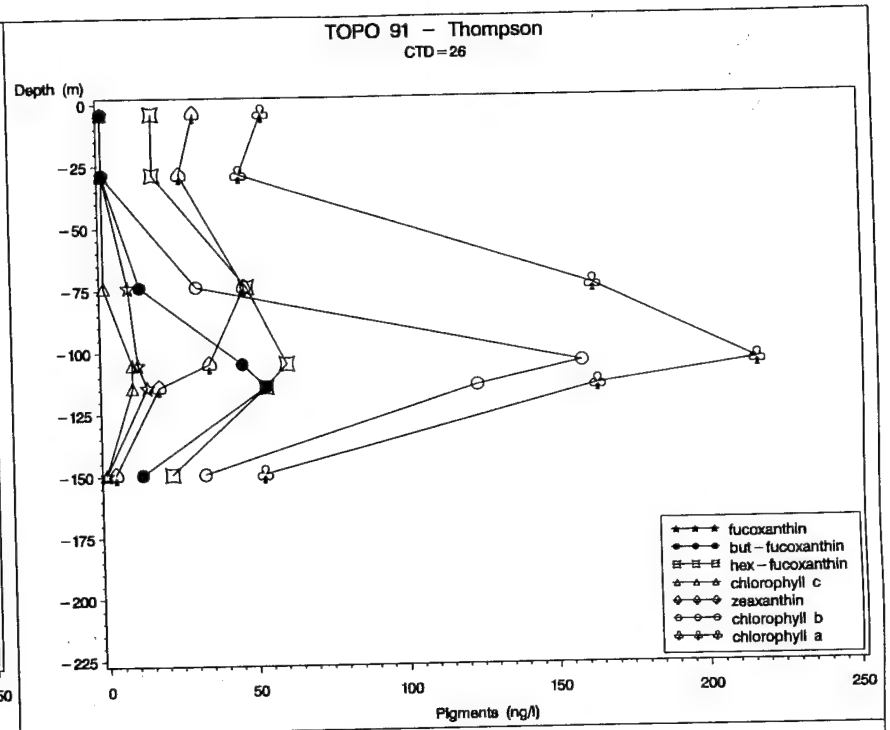

TOPO 91 – Thompson
CTD=21
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

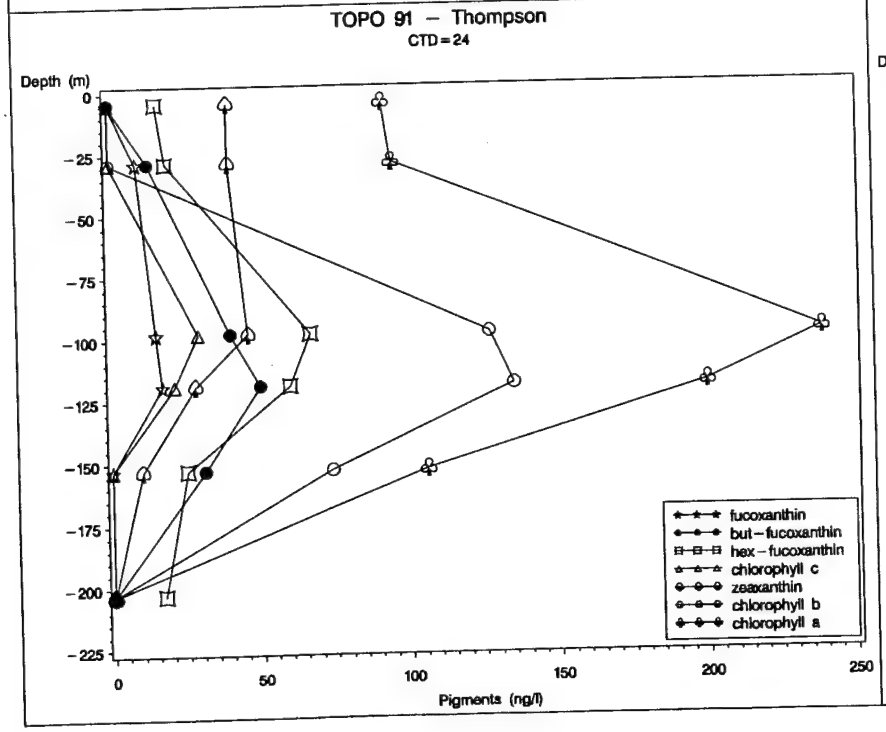

TOPO 91 – Thompson
CTD=22
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

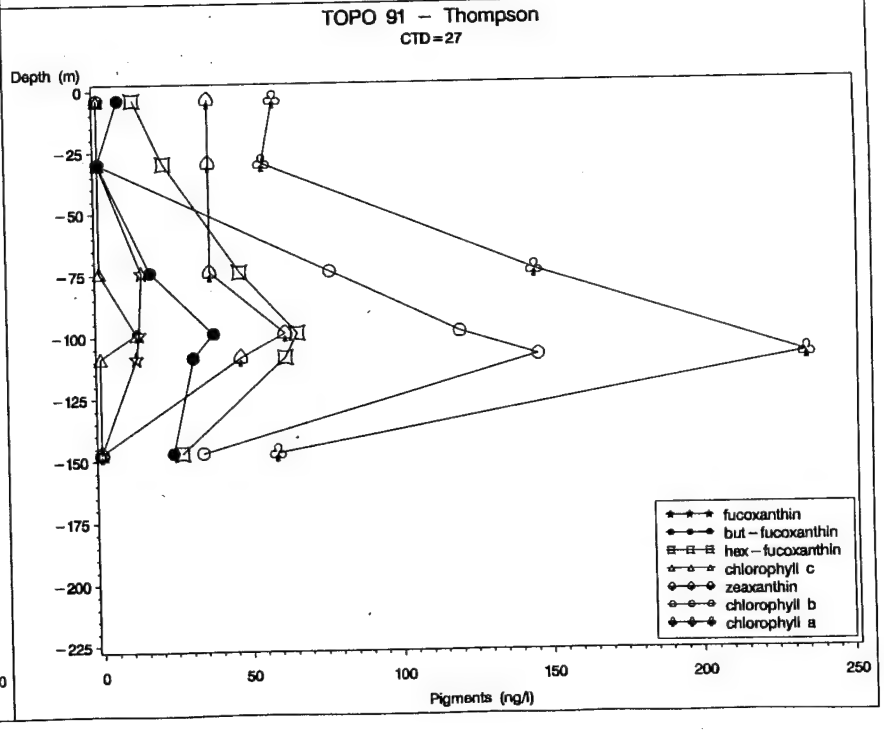

TOPO 91 – Thompson
CTD=20
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

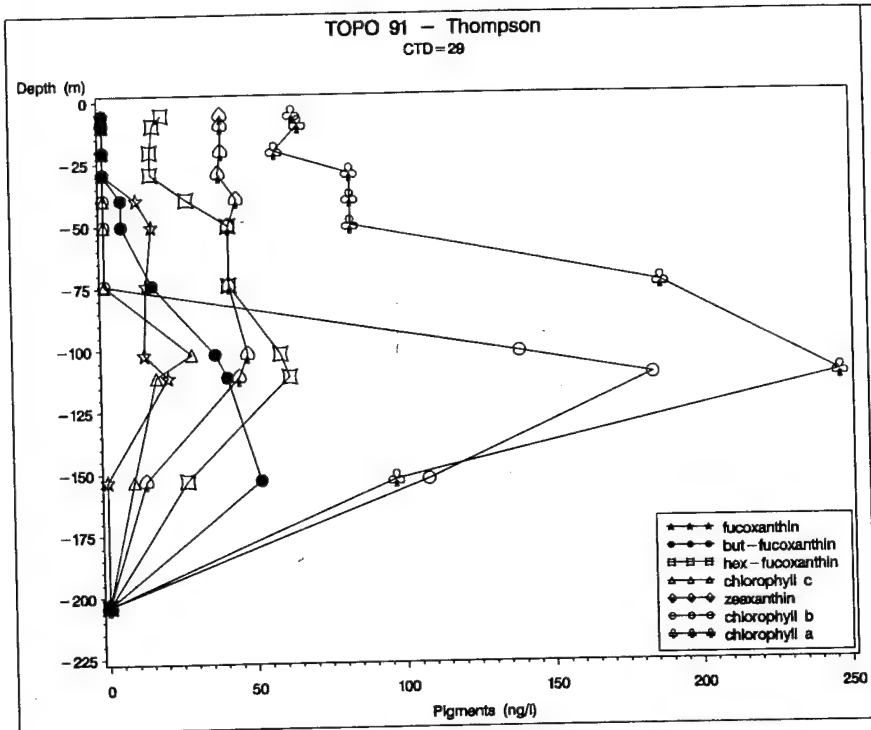

TOPO 91 – Thompson
CTD=23
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

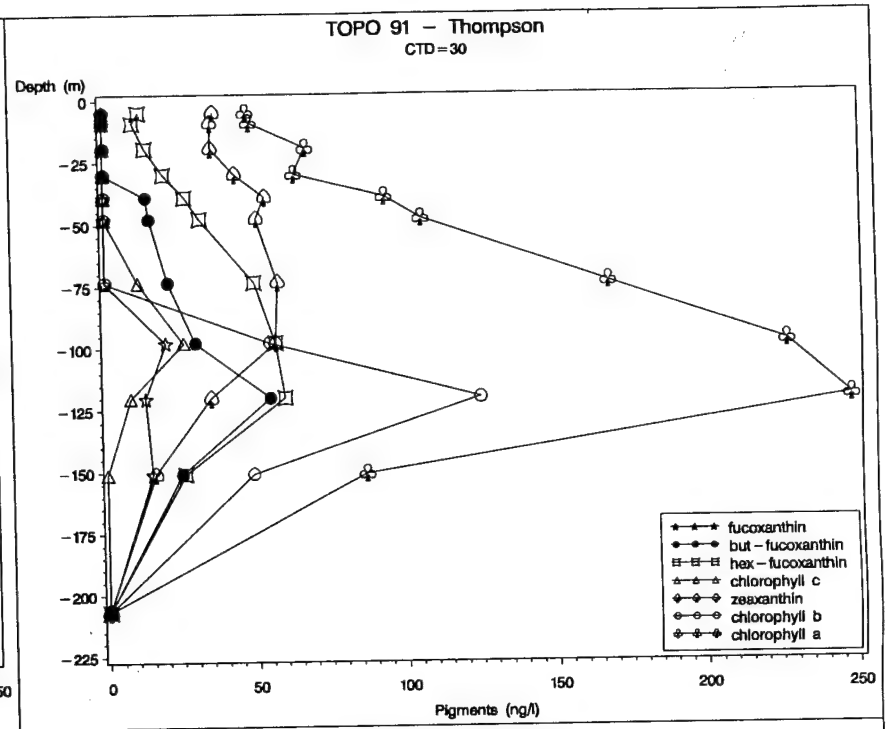

TOPO 91 – Thompson
CTD=25
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

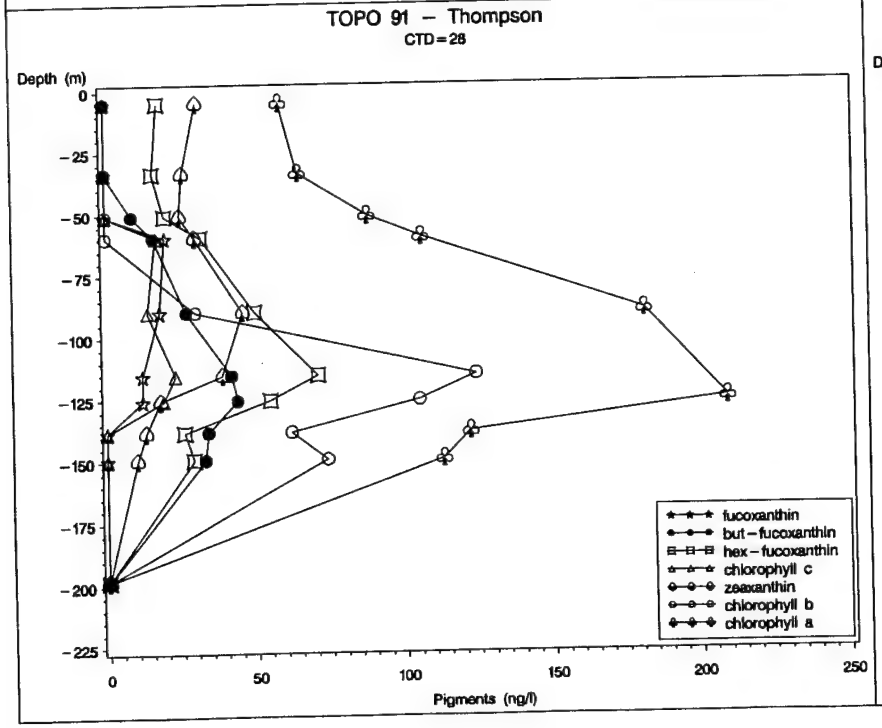

TOPO 91 – Thompson
CTD=26
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

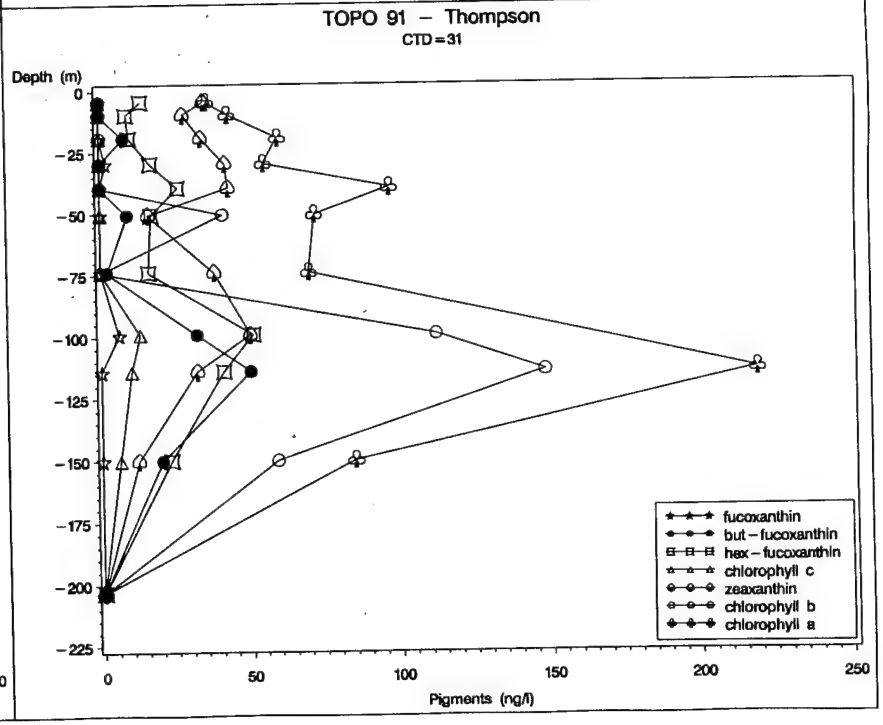

TOPO 91 – Thompson
CTD=24
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

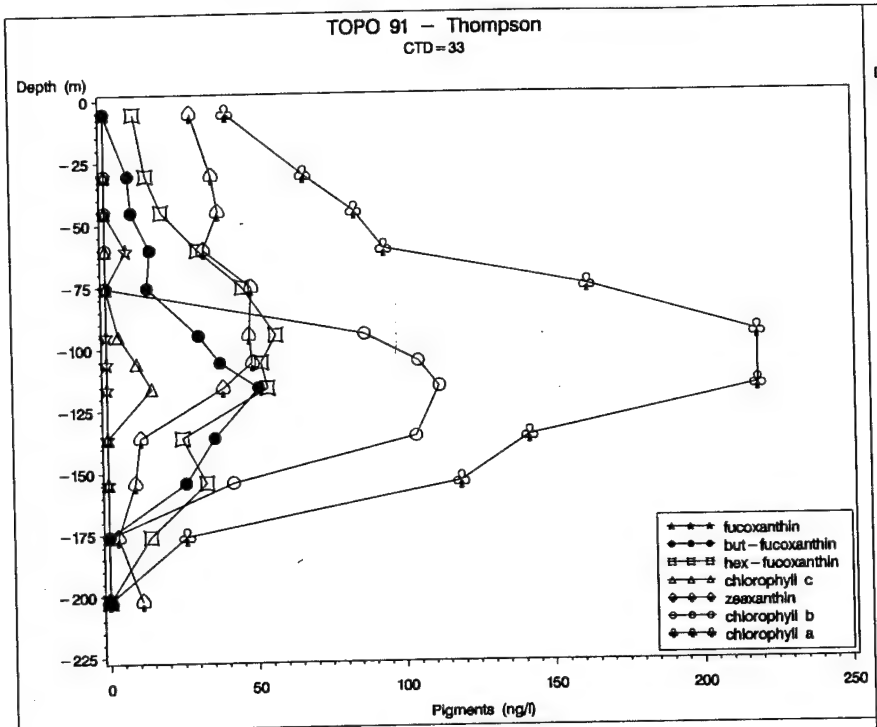

TOPO 91 – Thompson
CTD=27
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

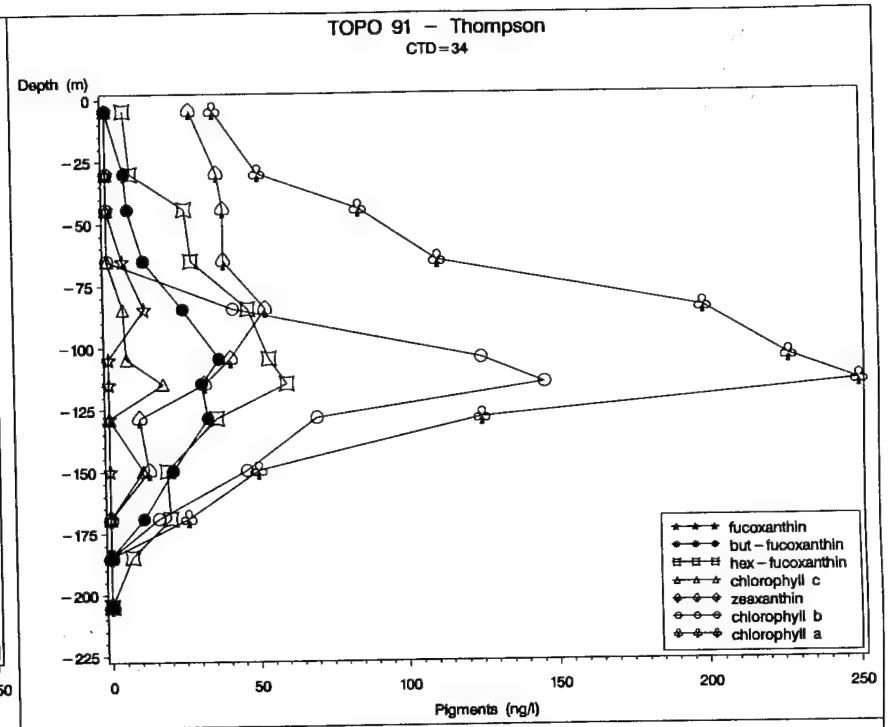

TOPO 91 – Thompson
CTD=29
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

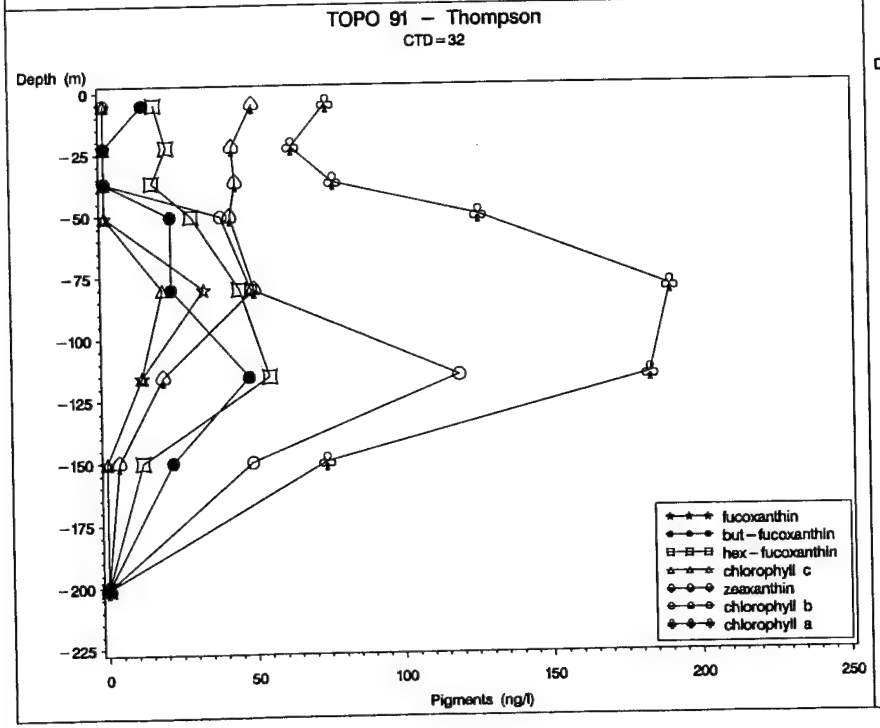

TOPO 91 – Thompson
CTD=30
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

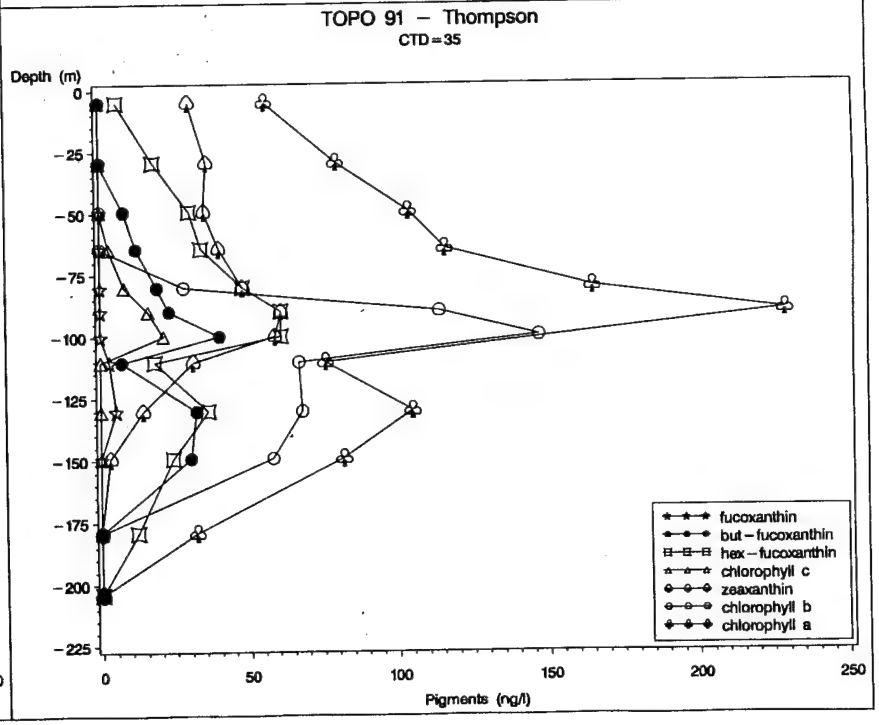

TOPO 91 – Thompson
CTD=28
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

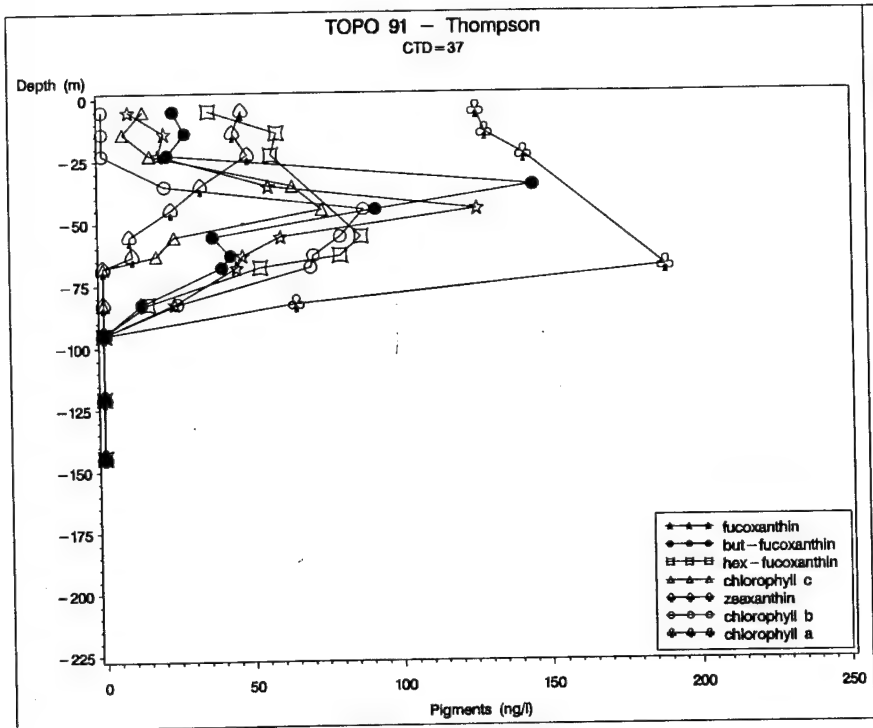

TOPO 91 – Thompson
CTD=31
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

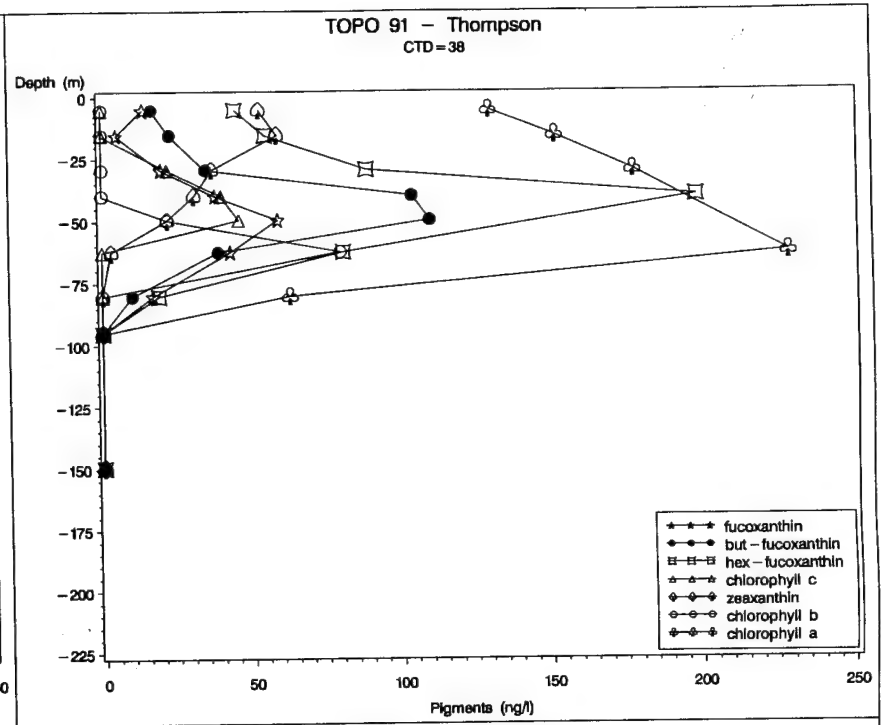

TOPO 91 – Thompson
CTD=33
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

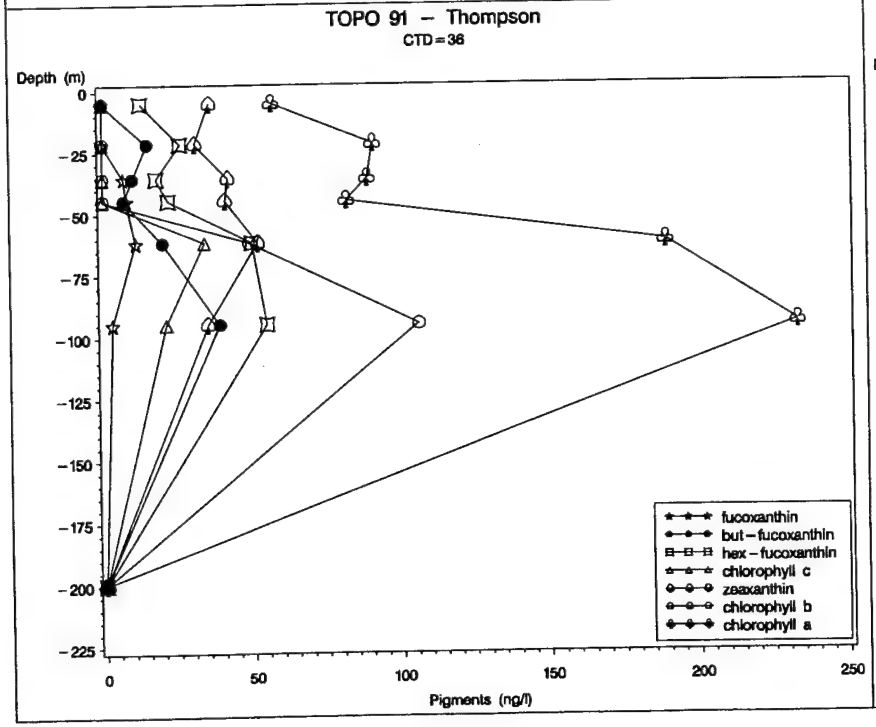

TOPO 91 – Thompson
CTD=34
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

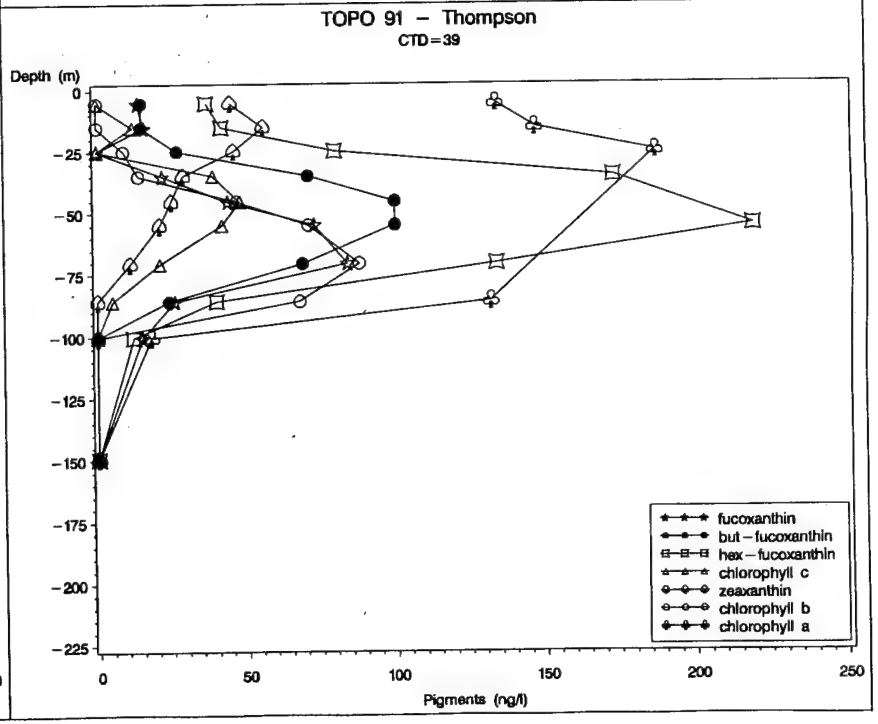

TOPO 91 – Thompson
CTD=32
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

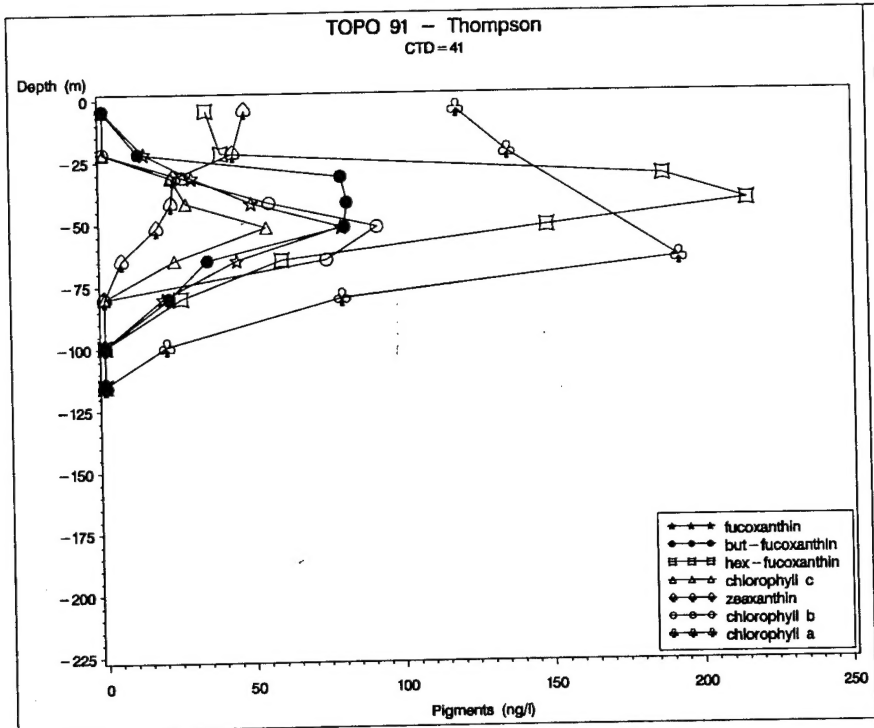

TOPO 91 – Thompson
CTD=35
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

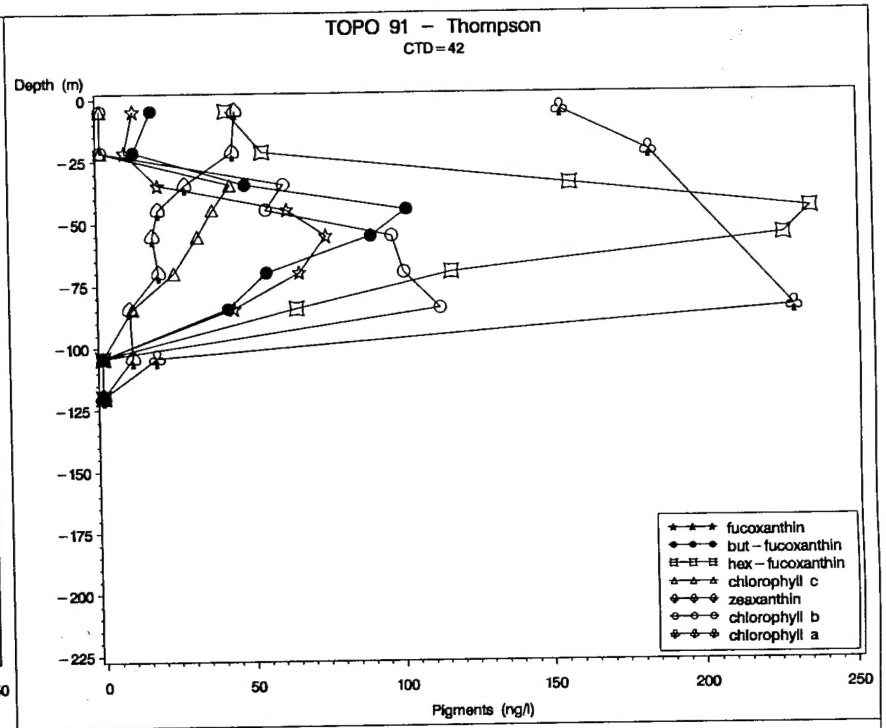

TOPO 91 – Thompson
CTD=37
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

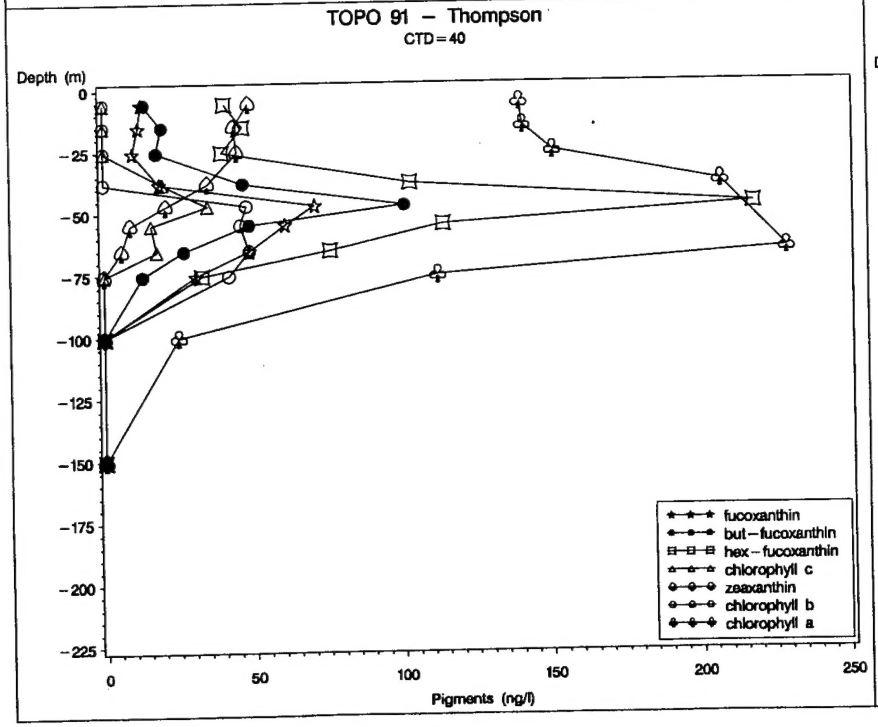

TOPO 91 – Thompson
CTD=38
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

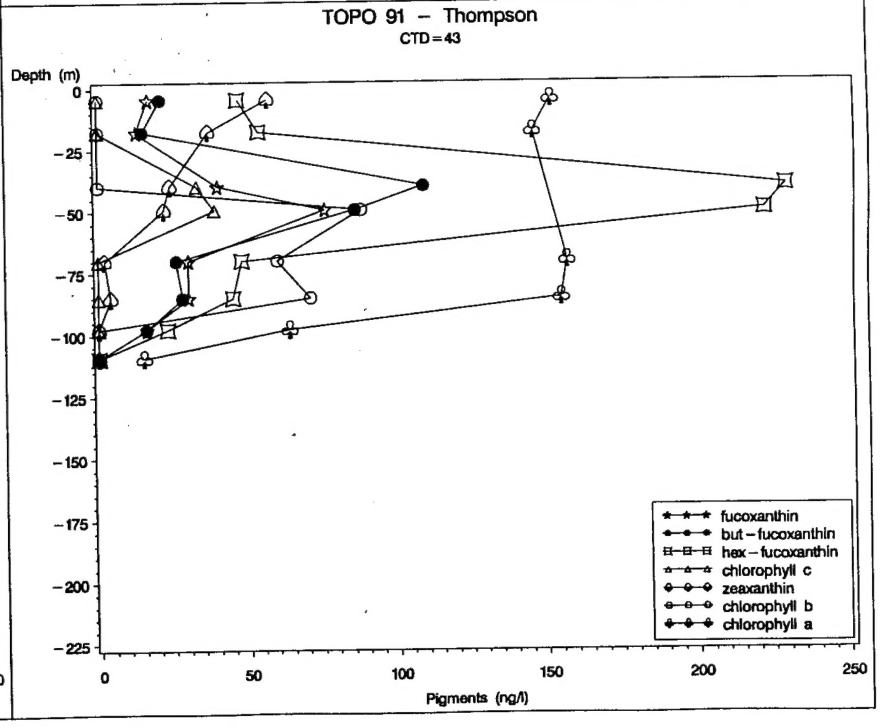

TOPO 91 – Thompson
CTD=36
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

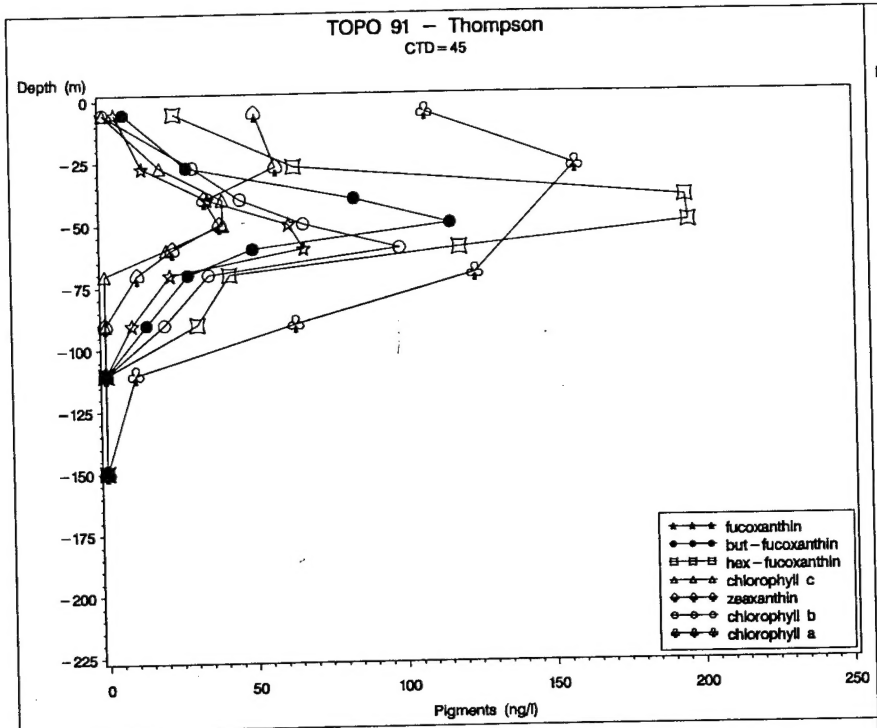

TOPO 91 – Thompson
CTD=39
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

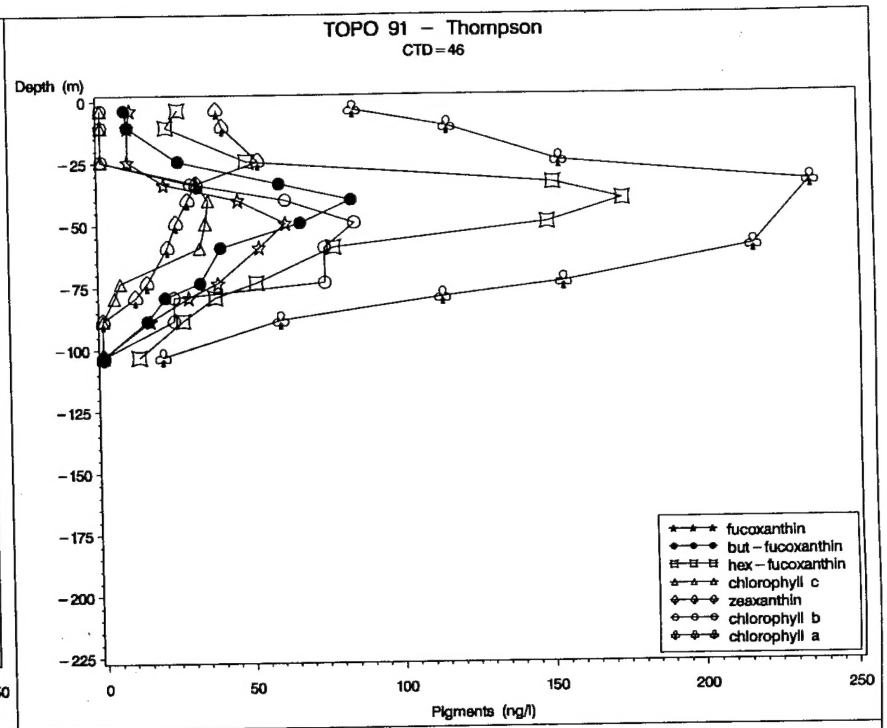

TOPO 91 – Thompson
CTD=41
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

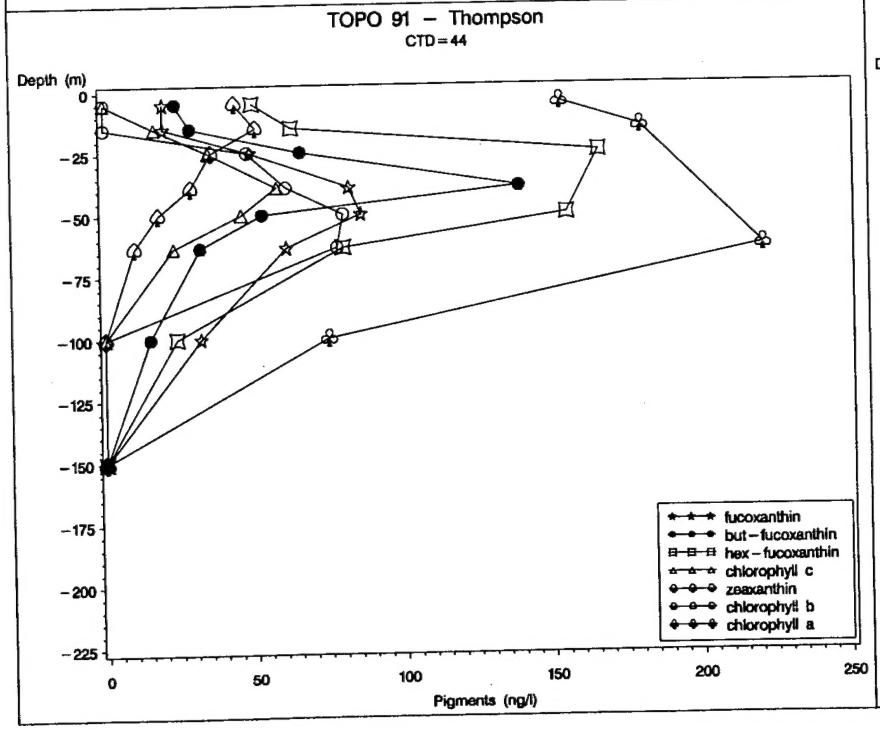

TOPO 91 – Thompson
CTD=42
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

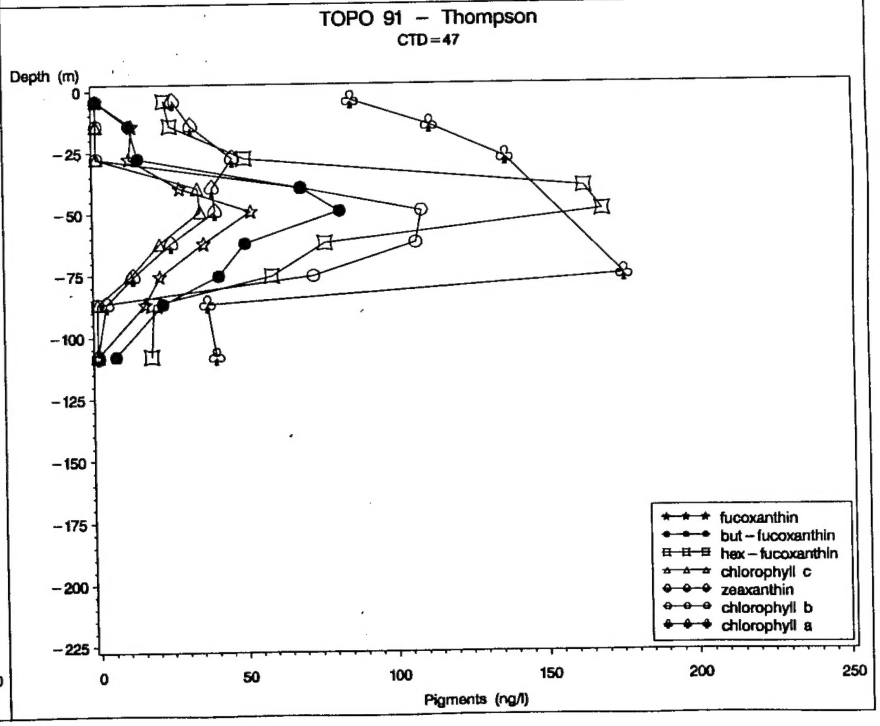

TOPO 91 – Thompson
CTD=40
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

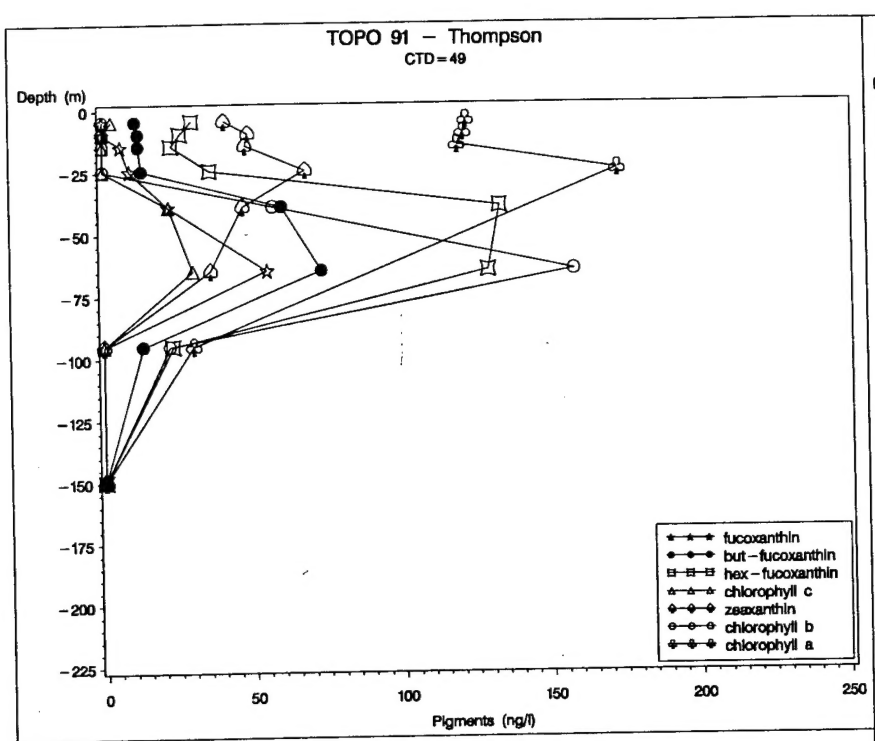

TOPO 91 – Thompson
CTD=43
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

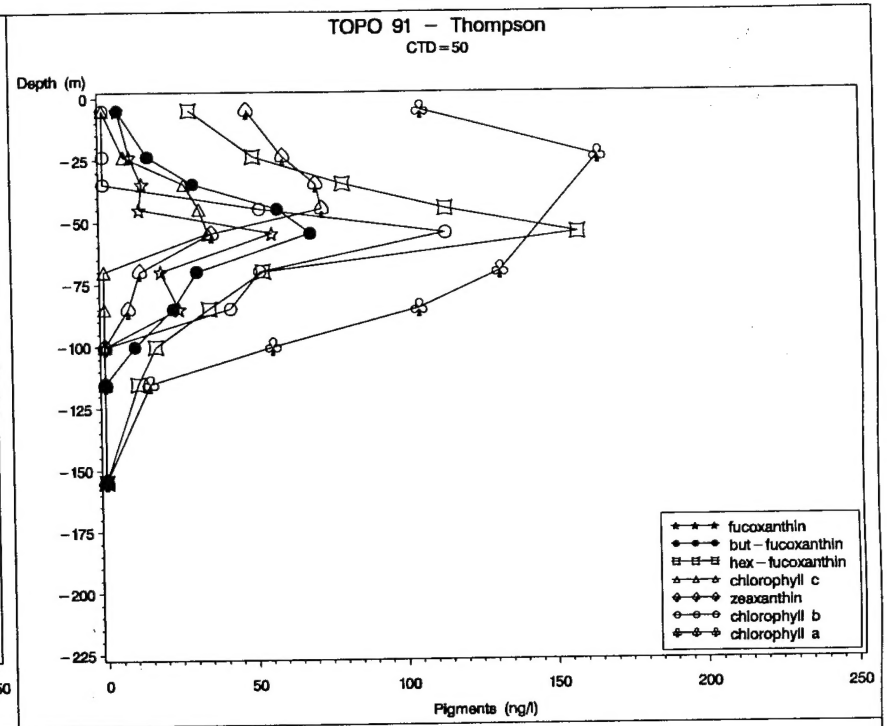

TOPO 91 – Thompson
CTD=45
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

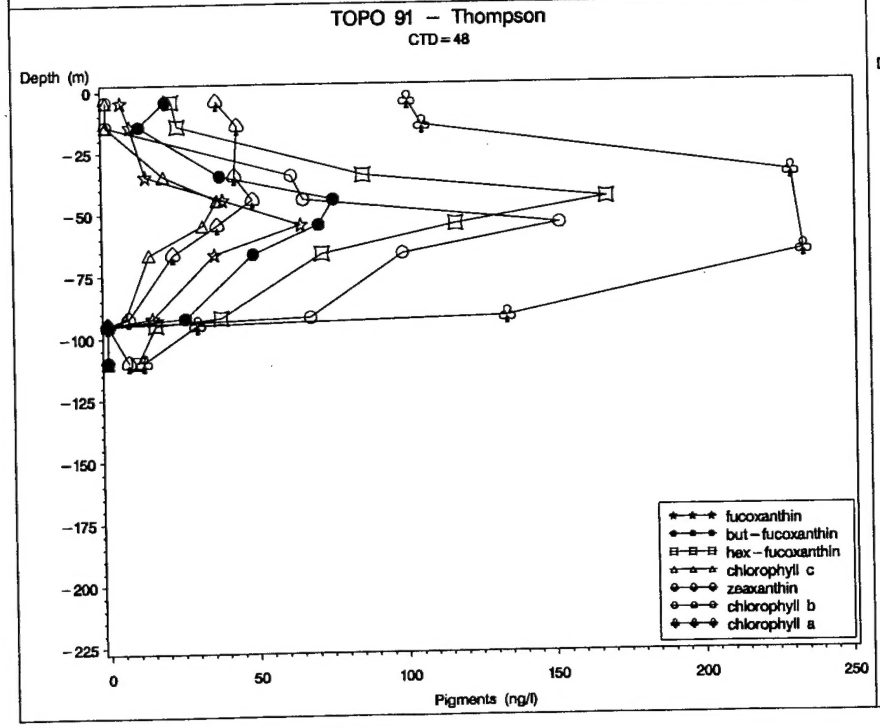

TOPO 91 – Thompson
CTD=46
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

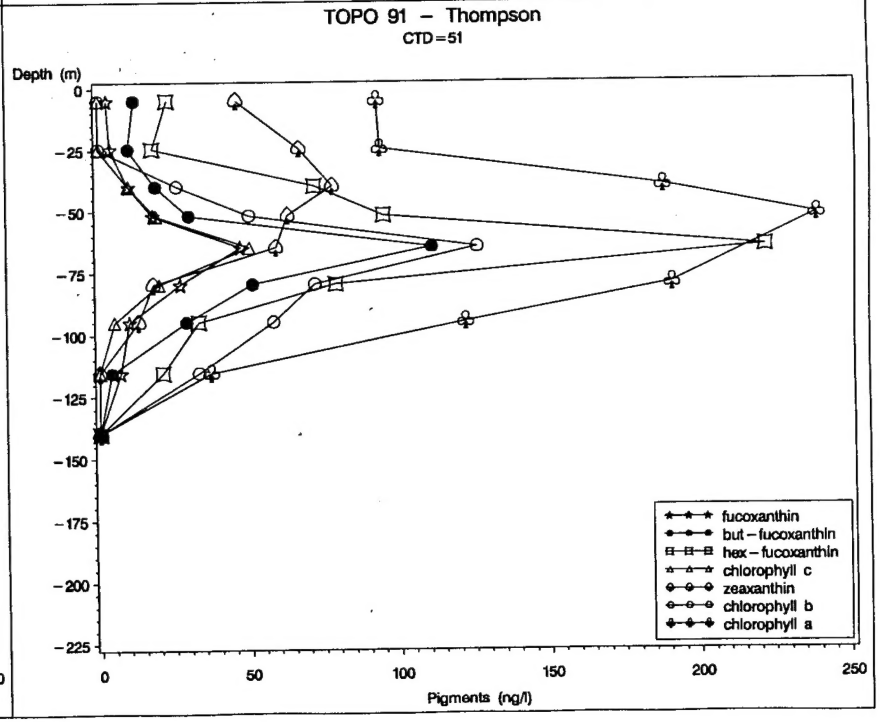

TOPO 91 – Thompson
CTD=44
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

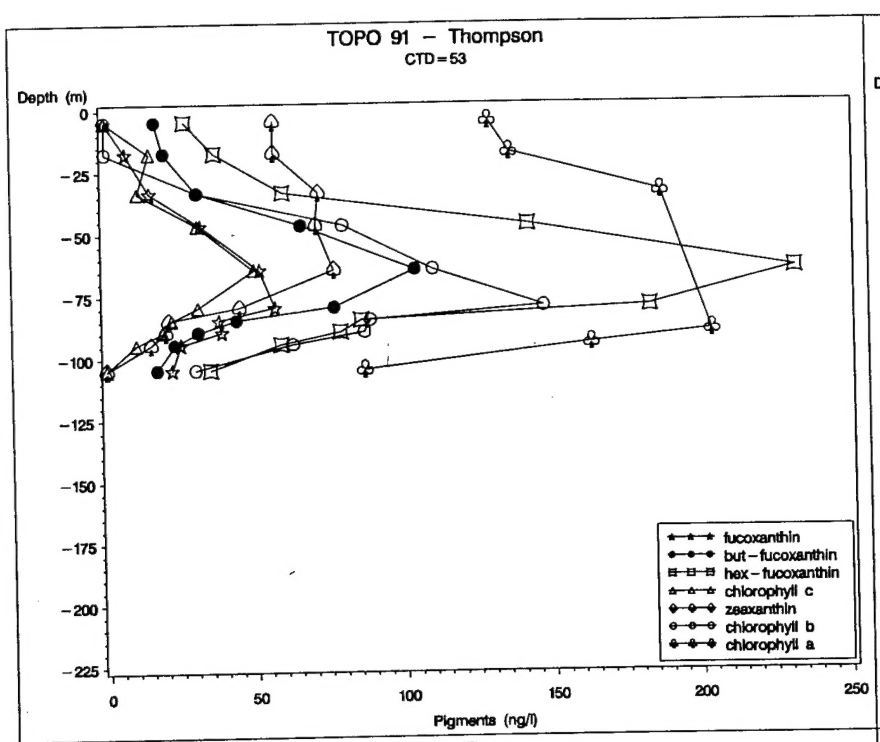

TOPO 91 – Thompson
CTD=47
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

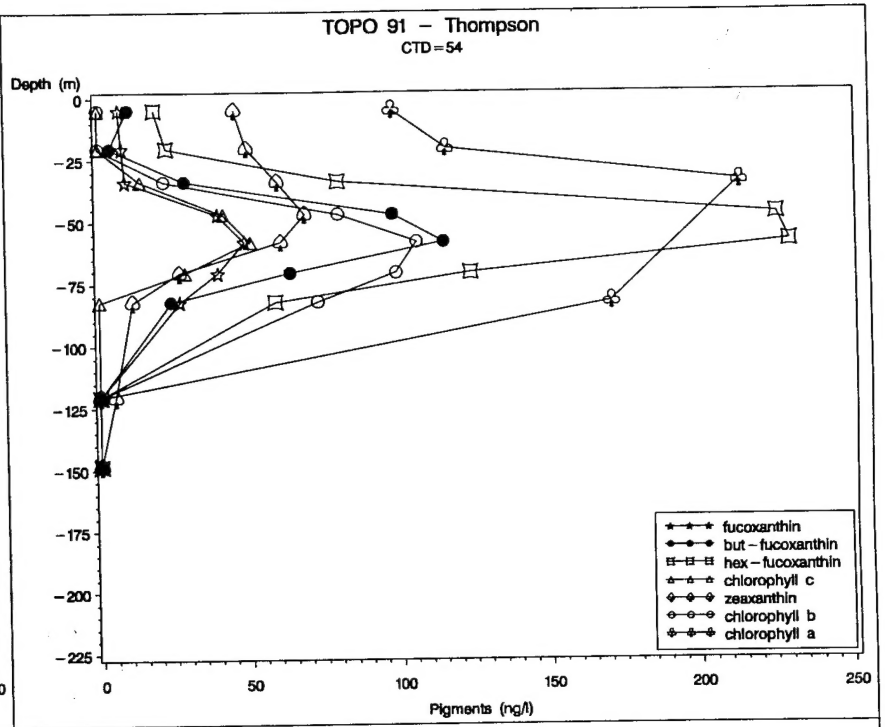

TOPO 91 – Thompson
CTD=49
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

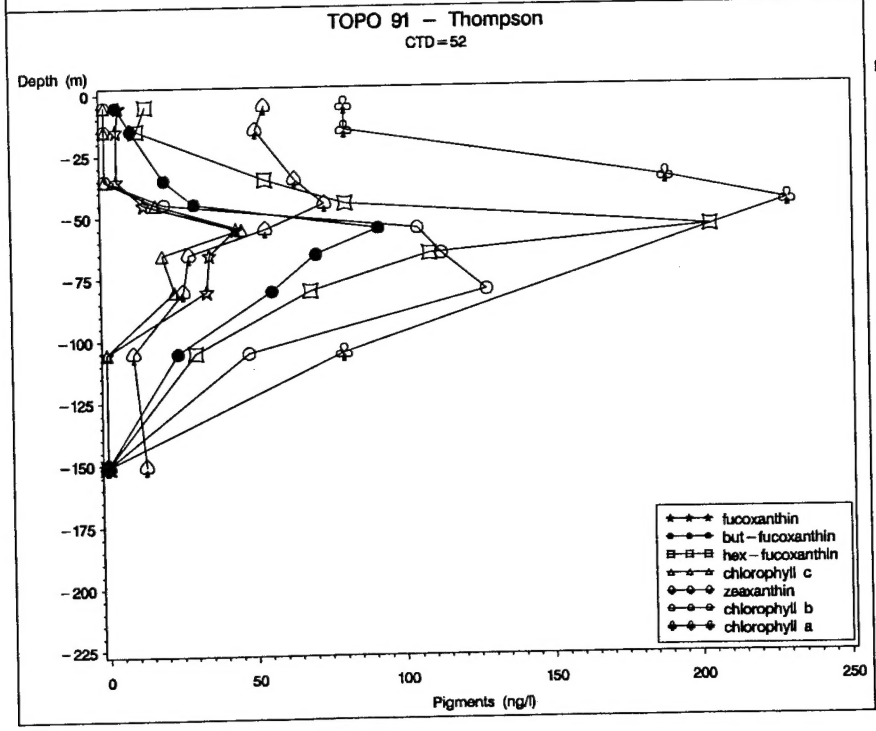

TOPO 91 – Thompson
CTD=50
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a

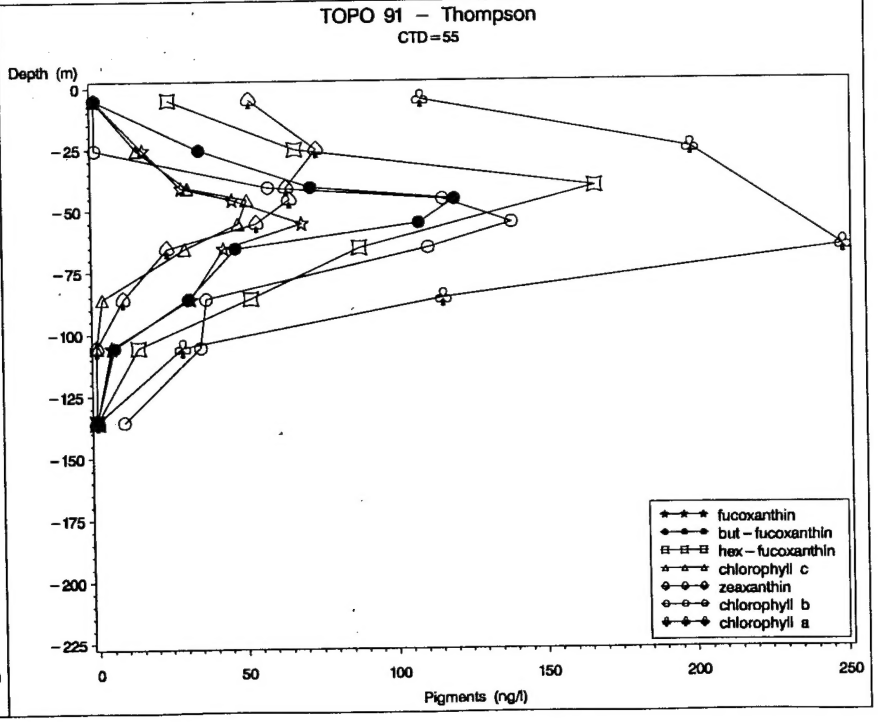

TOPO 91 – Thompson
CTD=48
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a


TOPO 91 – Thompson
CTD=51
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a


TOPO 91 – Thompson
CTD=53
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a


TOPO 91 – Thompson
CTD=54
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a


TOPO 91 – Thompson
CTD=52
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a


TOPO 91 – Thompson
CTD=55
Depth (m)
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
0
50
100
150
200
250
Pigments (ng/l)
fucoxanthin
but-fucoxanthin
hex-fucoxanthin
chlorophyll c
zeaxanthin
chlorophyll b
chlorophyll a